HURRICANE SURVEY

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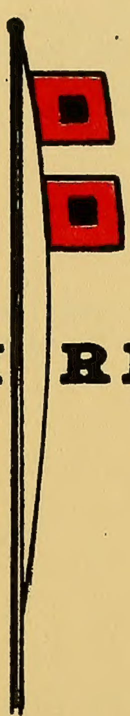

INTERIM REPORT

NARRAGANSETT BAY AREA

RHODE ISLAND
MASSACHUSETTS

Corps of Engineers, U.S. Army - Office of the Division Engineer

New England Division - Boston, Mass.

15 FEBRUARY 1957

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CORPS OF ENGINEERS, U.S. ARMY
OFFICE OF THE DIVISION ENGINEER
NEW ENGLAND DIVISION
150 Causeway Street
Boston 14, Mass.

NEDGW

21 March 1957

SUBJECT: Interim Report, Hurricane Survey, Narragansett Bay Area, Rhode Island and Massachusetts

TO: Division Engineer
South Atlantic Division
536 Old Post Office Building
Atlanta 1, Georgia

1. In compliance with instructions from the Chief of Engineers, eight (8) copies of the Interim Report, Hurricane Survey, Narragansett Bay Area, Rhode Island and Massachusetts, prepared by this office, are inclosed under separate cover.

2. The report has been prepared pursuant to the authorization contained in Public Law 71, 84th Congress, and is one of a series of reports which, when completed, will constitute a survey of the coastal area of New England subject to hurricane tidal flooding.

3. As the report has not yet been approved by the Chief of Engineers, the contents are not for public release.

FOR THE DIVISION ENGINEER:

1 Incl.
Rpt, Narra Bay,
w/Appendices and
WES Supplement
(Copies 36 thru 43)
(Under separate cover)

MILES L. WACHENDORF
Lt. Col., Corps of Engineers
Executive Officer

Lib. 43,623

HURRICANE SURVEY

INTERIM REPORT

NARRAGANSETT BAY AREA

RHODE ISLAND
MASSACHUSETTS

Corps of Engineers, U.S. Army - Office of the Division Engineer

New England Division - Boston, Mass.

15 FEBRUARY 1957

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No.	Title	To Accompany
B-1	Protection of Narragansett Bay from Hurricane Tides: Interim Report on Hydraulic Model Investigations	Appendix B

GLOSSARY

HURRICANE SURGE: the mass of water causing an increase in elevation of the water surface above predicted astronomical tide at the time of a hurricane; it includes wind set-up; sometimes the maximum increase in elevation is referred to as the surge.

HURRICANE TIDE: the rise and fall of the water surface during a hurricane, exclusive of wave action.

KNOT: a velocity equal to one nautical mile (6080.2 ft.) per hour (about 1.15 statute miles per hour).

OVERTOPPING: that portion of the wave runup which goes over the top of a protective structure.

PONDING: the storage of water behind a dike or wall from local runoff and/or overtopping by waves.

POOL BUILDUP: the increase in elevation of water surface behind a structure due to runoff and/or overtopping by waves.

RUNUP: the rush of water up the face of a structure on the breaking of a wave. The height of runup is measured from the still-water level.

SIGNIFICANT WAVE: a statistical term denoting waves with the average height and period of the one-third highest waves of a given wave train.

SPRING TIDE: a tide that occurs at or near the time of new and full moon and which rises highest and falls lowest from the mean level.

STILL WATER LEVEL: the elevation of the water surface if all wave action were to cease.

STORM SURGE: same as "hurricane surge."

WAVE HEIGHT: the vertical distance between the crest and preceding trough.

WAVE TRAIN: a series of waves from the same direction.

WIND SET-UP: the vertical rise in the stillwater level on the leeward side of a body of water caused by wind stresses on the surface of the water.

BUILDUP BELOW BARRIER: the increase in water surface elevation in feet immediately downstream from the barrier resulting from construction of the barrier.

SYLLABUS

The Division Engineer finds that a serious problem of hurricane tidal flooding exists in the densely populated Narragansett Bay area. The acuteness of this problem is indicated by the fact that tidal flood damages in the area in 1954 totalled $92,000,000. A recurrence of the hurricane tidal flooding that has been experienced in the past twenty years would cause damages totalling approximately $220,000,000 at 1956 price levels. He concludes that protective barriers in Narragansett Bay are economically justified.

The Division Engineer recommends a two-unit solution of the problem:

a. For the protection of the City of Providence, Rhode Island, the immediate construction of a concrete barrier and pumping station across the Providence River at Fox Point in Providence. The estimated cost is approximately $16,500,000 at present day prices.

b. For the general protection of Narragansett Bay, the construction of rock-fill barriers across the East and West Passages in Lower Narragansett Bay and a barrier across the Sakonnet

River at Tiverton, subject to more detailed design studies of the structures and their effects on navigation, pollution and fisheries. The estimated cost of these barriers, based on optimum foundation conditions, is $69,000,000. Some revision of this estimated cost may be expected upon completion of the detailed design studies which the Division Engineer recommends. Under the most unfavorable foundation conditions the estimated cost of these barriers is $109,000,000.

U.S. ARMY ENGINEER DIVISION, NEW ENGLAND
CORPS OF ENGINEERS
150 Causeway Street
Boston 14, Mass.

NEDGW 15 February 1957

SUBJECT: Interim Report on Hurricane Survey, Narragansett Bay, Rhode Island and Massachusetts

TO: Chief of Engineers
Department of the Army
Washington 25, D.C.
ATTENTION: ENGWF

AUTHORITY

1. This report is submitted in partial compliance with authorization contained in Public Law 71, 84th Congress, 1st session, adopted 15 June 1955, which reads:

"Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled. That in view of the severe damage to the coastal and tidal areas of the eastern and southern United States from the occurrence of hurricanes, particularly the hurricanes of August 31, 1954, and September 11, 1954, in the New England, New York, and New Jersey coastal and tidal areas, and the hurricane of October 15, 1954, in the coastal and tidal areas extending south to South Carolina, and in view of the damages caused by other hurricanes in the past, the Secretary of the Army, in cooperation with the Secretary of Commerce and other Federal agencies concerned with hurricanes, is hereby authorized and directed to cause an examination and survey to be made of the eastern and southern seaboard of the United States with respect to hurricanes, with particular reference to areas where severe damages have occurred.

SEC. 2. Such survey, to be made under the direction of the Chief of Engineers, shall include the securing of data on the behavior and frequency of hurricanes, and the determination of methods of forecasting their paths and improving warning services, and of possible means of preventing loss of human

lives and damages to property, with due consideration of the economics of proposed breakwaters, seawalls, dikes, dams, and other structures, warning services, or other measures which might be required."

SCOPE OF SURVEY

2. GENERAL

This interim report of survey scope comprises the results of an examination and survey of hurricane tidal flooding in the Narragansett and Mount Hope Bay areas of Rhode Island and Massachusetts. It is one report of a series in preparation which, when completed, will constitute a full survey of the coastal areas of New England subject to tidal flooding from hurricanes. In the preparation of this report, extensive basic data was collected and analyzed because of the limited information available on hurricane tidal flooding when the survey was initiated. All available data on tidal hydraulics, hurricane characteristics, past hurricanes in the area, and the oceanography of Narragansett Bay were utilized. Various engineering and special studies were carried out, and work was coordinated with various Federal, state and local agencies.

3. ENGINEERING STUDIES

Detailed hydrographic surveys were made as a basis for analytical and experimental studies of protective works in Narragansett Bay, both for hurricane tide and normal tide conditions. Field investigations were made of tidal flood damages in the entire survey area. Field investigations also included topographic surveys, soundings and borings for each of the barrier sites investigated, except that in the deep waters of the Lower Bay seismic investigations of foundation conditions were made instead of borings. All of the many plans of protection proposed by interested parties were considered in order to determine the most practical and economical means of protection against tidal flooding. The more suitable plans were thoroughly investigated, and designs and estimates of costs and benefits prepared.

4. SPECIAL STUDIES

A hydraulic model of Narragansett Bay, 250 feet in length and 100 feet in width, at the Waterways Experiment Station in Vicksburg, Mississippi, was used to investigate the characteristics of normal and hurricane tides in the bay and the effectiveness of barriers in reducing hurricane flood levels. The Beach Erosion Board, assisted by the Texas A&M Research Foundation, using data on maximum hurricane

wind velocities and durations obtained from the U.S. Weather Bureau, assisted in studies of a design hurricane flood. Limited studies were made of the behavior and characteristics of hurricanes. Studies were made of wave action and the effect of barriers in the Lower Bay on navigation, pollution and fisheries. The Narragansett Marine Laboratory of the University of Rhode Island contributed to these studies.

5. COORDINATION

This report has been prepared with the cooperation of various Federal, state and local agencies, who have assisted in furnishing information and advice in the solution of the many complicated problems of the survey. Public hearings were held at Providence, Newport and Fall River to acquaint the people in the area with the results of the survey and to enable them to present their views thereon. Details of coordination with other agencies are described in paragraph 74.

PRIOR REPORTS

6. HURRICANE REPORTS

There are no previous reports by the Corps of Engineers specifically on the subject of hurricanes and hurricane protection in the Narragansett Bay area. Part II, Chapter XXXIX, of the unpublished report of the New England-New York Inter-Agency Committee on "The Resources of the New England-New York Region", prepared pursuant to a Presidential directive of October 9, 1950, contains a section devoted to hurricanes in the northeastern United States. The general nature and extent of damages caused in the region by the hurricanes of September 21, 1938; September 14, 1944; August 31, 1954 (Carol); September 11, 1954 (Edna) and October 16, 1954 (Hazel) are discussed therein, together with the problems of establishing protective measures.

7. NAVIGATION REPORTS

Numerous reports have been prepared and submitted for the improvement of many of the channels and harbors in the Narragansett Bay area and others are in preparation.

a. Among the more recent reports, which have been the basis for authorized projects, are the following:

Report	Project
Providence River and Harbor, R.I. Review Report: H.D. No. 173, 75th Congress, 1st session.	Dredging 35-foot approach channel from deep water in Narragansett Bay to Fox Point. Adopted August 26, 1937. Project completed in 1950.
Wickford Harbor, R.I. Survey report: S.D. No. 141, 79th Congress, 2nd session.	Construction of breakwaters and maintenance of channel. Approved 24 July 1946. Project completed in 1949.
Taunton River, Mass. Survey report: H.D. No. 403, 71st Congress, 2nd session; Survey Report: H.D. No. 196, 80th Congress, 1st session.	Channel 12 feet deep to Taunton Municipal wharf; a small craft anchorage 8 feet deep at Dighton; and turning basin 12 feet deep at Taunton. Adopted 3 July 1930 and 30 June 1948.
Sakonnet Harbor, R.I. Survey report: H.D. No. 436, 82nd Congress, 2nd session.	Provides for extension of existing breakwater and dredging of harbor. Approved 3 September 1954.
Bullocks Point Cove, R.I. Survey report: H.D. No. 242, 83rd Congress, 2nd session.	Provides for breakwater and jetty, dredged channel and anchorage areas. Authorized 3 September 1954.

b. Reports currently being prepared which consider various improvements within the Narragansett Bay area are the following:

Newport Harbor, R.I. Survey report: River and Harbor Act of 24 July 1946.	To determine feasibility of improving navigation by deepening part of waterfront channel and providing a small-boat basin.
Greenwich Cove, R.I. Preliminary examination and survey: House Resolution, adopted 16 August 1950.	To determine possibilities for development of a small-boat harbor.
Apponaug Cove, R.I. Survey report: House Resolution, adopted 27 June 1956.	To determine possibilities for development of a small-boat harbor.

Hydraulic model of Narragansett Bay constructed at Waterways Experiment Station, Vicksburg, Mississippi. Looking north from mouth of bay toward Providence. The model was a valuable tool in studies of tidal conditions in Narragansett Bay and the effectiveness of barriers in reducing hurricane flood levels.

Wickford Harbor, R.I. Review report: House Resolution adopted 27 June 1956.	To determine possibilities for further development of a small-boat harbor.

c. Other navigation studies authorized within the Narragansett Bay area on which reports will be prepared are the following:

Dutch Island Harbor, R.I. Preliminary examination: River and Harbor Act of 24 July 1946.	To determine possibilities for development of a small-boat harbor.
Pawtuxet Cove, R.I. Preliminary examination: House Resolution, adopted 5 April 1949.	To determine possibilities for development of a small-boat harbor.
Providence River and Harbor, R.I. Survey report: Senate Resolution, adopted 6 January 1950.	To determine feasibility of improving the harbor for commercial navigation.
Intracoastal Waterway, R.I. Preliminary examination: Senate Resolution, adopted 13 April 1950.	To determine possibilities for development of a navigable waterway, particularly through State of Rhode Island.
Bristol Harbor, R.I. Preliminary examination: House Resolution adopted 29 July 1955.	To determine possibilities for development of a small-boat harbor.
Seekonk River, R.I. Survey report: Senate Resolution, adopted 6 January 1950.	To determine feasibility of improving the river for commercial navigation.

DESCRIPTION

8. LOCATION AND EXTENT

The Narragansett Bay area includes about one-half of the total area of Rhode Island. The bay and connecting tidal waters form a deep indentation in the Rhode Island coastline between Point Judith on the west and Sakonnet Point on the east, extending three-fourths of the length of the state in a northerly direction past Providence, the state capital (Plate 1). Mount Hope Bay, which extends northeast from Narragansett Bay proper into Massachusetts ten miles beyond the city of Fall River, and the Sakonnet River are considered part of Narragansett Bay for purposes of this report. To the south and southeast the bay lies directly exposed to the open ocean, making it vulnerable to the force of hurricane surges sweeping up the Atlantic coast. The shoreline is characteristically irregular and marked by numerous forelands, sandy beaches and inlets, and bold, rocky shores. Woodland and thick vegetation border the shore where it has not been developed for residential or industrial use.

The total area of the bay is about 176 square miles. From Brenton Point to Newport to Providence, along the main axis of the bay, the distance is about 26 miles. The width of the bay averages four to five miles. Three large islands, Aquidneck, Conanicut and Prudence Islands, - and about a half dozen smaller islands lie within the bay. Conanicut and Prudence Islands divide the main portion of the bay into two long and narrow parts known as the East and West Passages; Aquidneck Island separates the Sakonnet River from the East Passage.

9. TRIBUTARIES AND HARBORS

The most important streams tributary to Narragansett Bay are the Blackstone River; the Taunton River, with Fall River Harbor at its mouth; and the Providence River. The Blackstone River, which has its source in Worcester, Massachusetts, has a drainage area of 540 square miles. Its tidal reach is known as the Seekonk River. Portions of the Seekonk River and Providence River constitute Providence Harbor, which with Fall River Harbor are the two most important commercial ports in the area. Newport Harbor and Lower Narragansett Bay are of major importance to Naval vessels.

Flood waters of Hurricane "Carol" (August 1954) swept up the Providence River flooding industrial areas in Providence.

Photo by C. Demerjien

10. TIDES AND CURRENTS

Ocean tides enter the bay through the East and West Passages and the Sakonnet River. Two approximately equal tides occur each day, a tidal cycle averaging 12.4 hours. Mean tide ranges from 3.5 feet at Newport to 4.6 feet at Providence and spring tide from 4.4 feet at Newport to 5.7 feet at Providence. Tidal movement is nearly simultaneous throughout the bay, high and low tide for most points occurring within twenty minutes of high and low tide at Newport. High water at Providence occurs about 10 minutes after high water at Newport. The usual maximum flood or ebb current is from 0.5 to 1.0 knot; however, in narrow areas of the bay, the current is as much as 2.75 knots as at the Sakonnet River bridges. For spring tides, the usual maximum velocities are about 20 percent greater than the above values.

11. GENERAL GEOLOGY AND TOPOGRAPHY

a. Structure. The bedrock of the eastern and southeastern seaboard lowland of New England is predominantly gneissic and granitic, except where complicated by the presence of schist, as in the case of southwestern Rhode Island, or where a low spot in the crystallines contains residual younger sedimentary rocks. Many of the igneous rocks have been attributed to the Devonian Period, while rocks in the two most prominent depressions, the Boston Basin and the Narragansett Basin, are largely carboniferous; thus the entire area is predominantly lower to middle Paleozoic in age.

Glaciation and stream erosion were much more effective in the sedimentary rocks of the basin than in the surrounding crystallines, and caused the entire basin to exist as a depression. Narragansett Bay, however, occupies merely the southwestern portion of the basin, and represents the surface flooding of some of the deeper valleys of the depression. Attempts have been made to visualize distinct structures in the basin. The rocks have been described as dipping steeply in a series of broken synclines and a rough estimate of two miles has been ventured for the thickness of Carboniferous strata represented in the basin, but the interpretation involved postulation of numerous faults, and appears somewhat contrived.

b. The rocks of Narragansett Bay. The rocks of the bay are largely sandstones and shales, sometimes coaly, as in the deposits of the old "coal" mine north of Newport. Mineral alteration is quite pronounced locally, presumably owing to adjacent granitic contacts north of the entrance to Mount Hope Bay, Newport Head, the southern tip of Jamestown Island, and the coast of Narragansett, the latter granite having been established only rather recently as a younger intrusional body.

Rock surface beneath the bottom sediments of the bay is highly irregular, attaining minus elevations of about 400 feet in places, with adjacent areas forming shallow rock pavements with almost no sediment cover, the rough structural configuration having been complicated by extensive pre-glacial erosion to form gorges now under a deep cover of glacial and post-glacial sediments.

c. The sediments of Narragansett Bay. Borings indicate that the glaciers swept the bay, leaving a cover of their own, quite thick in places. The usual resulting sequence up-bay, resting on bedrock, is cobbles and boulder clay or reworked till, a considerable thickness of outwash silts and sands, capped by a few to fifteen feet of organic silts of recent origin; while deep gorges in the middle and lower bay areas trapped accumulations of silts and clays, sometimes in excess of 100 feet.

d. Topography. Topography is governed by geological structure in that heavy outwash deposits from East Greenwich to Quonset provide a low flat plain; fluvio - glacial sands east of Point Nayatt present a slightly and undulating terrace; and projections of the old sedimentary rock structure stand out as moderately high islands. Maximum elevations of about 300 feet occur where the crystalling old land nears the bay, notably west of Greenwich Bay. Maximum elevations within the basin attain about 125 feet.

12. AREA MAPS

The area under study appears on standard quadrangle sheets of the U. S. Geological Survey at a scale of 1:31,680 and on a Geological Survey topographic map of the states of Massachusetts, Rhode Island and Connecticut at a scale of 1:500,000. The area is also shown on the Providence topographic sheet of the Army Map Service at a scale of 1:250,000. Narragansett Bay and the navigable parts of its tributary streams appear on U. S. Coast and Geodetic Survey charts Nos. 236, 278, 352, 353, and 1210, which are now being revised (1956). The Coast and Geodetic Survey is also preparing detail maps, at a contour interval of one foot, of areas in Providence subject to tidal flooding.

ECONOMIC DEVELOPMENT

13. POPULATION

Narragansett Bay lies in one of the most densely populated areas of the country. In density of population, Rhode Island ranks first and Massachusetts third in the United States. The population of the Narragansett Bay area is more than 725,000 (1950 census), including 586,000 in the Rhode Island portion and 139,000 in the Massachusetts portion. Approximately 85 percent of this population is urban. Populations by towns are given in Table 1 and the distribution of the population is shown in Figure 1.

TABLE 1

POPULATION OF CITIES AND TOWNS
NARRAGANSETT BAY AREA

(1950 Census)

City or Town	Population
Providence, R.I.	248,674
Fall River, Mass.	111,963
Pawtucket, R.I.	81,436
Cranston, R.I.	55,060
Warwick, R.I.	43,028
Newport, R.I.	37,564
East Providence, R.I.	35,871
North Kingstown, R.I.	14,810
Bristol, R.I.	12,320
South Kingstown, R.I.	10,148
Somerset, Mass.	8,566
Warren, R.I.	8,513
Barrington, R.I.	8,246
Middletown, R.I.	7,382
Portsmouth, R.I.	6,578
Swansea, Mass.	6,129
Seekonk, Mass.	6,104
Tiverton, R.I.	5,659
East Greenwich, R.I.	4,923
Dighton, Mass.	2,950
Narragansett, R.I.	2,288
Freetown, Mass.	2,104

TABLE 1 (continued)

POPULATION OF CITIES AND TOWNS,
NARRAGANSETT BAY AREA

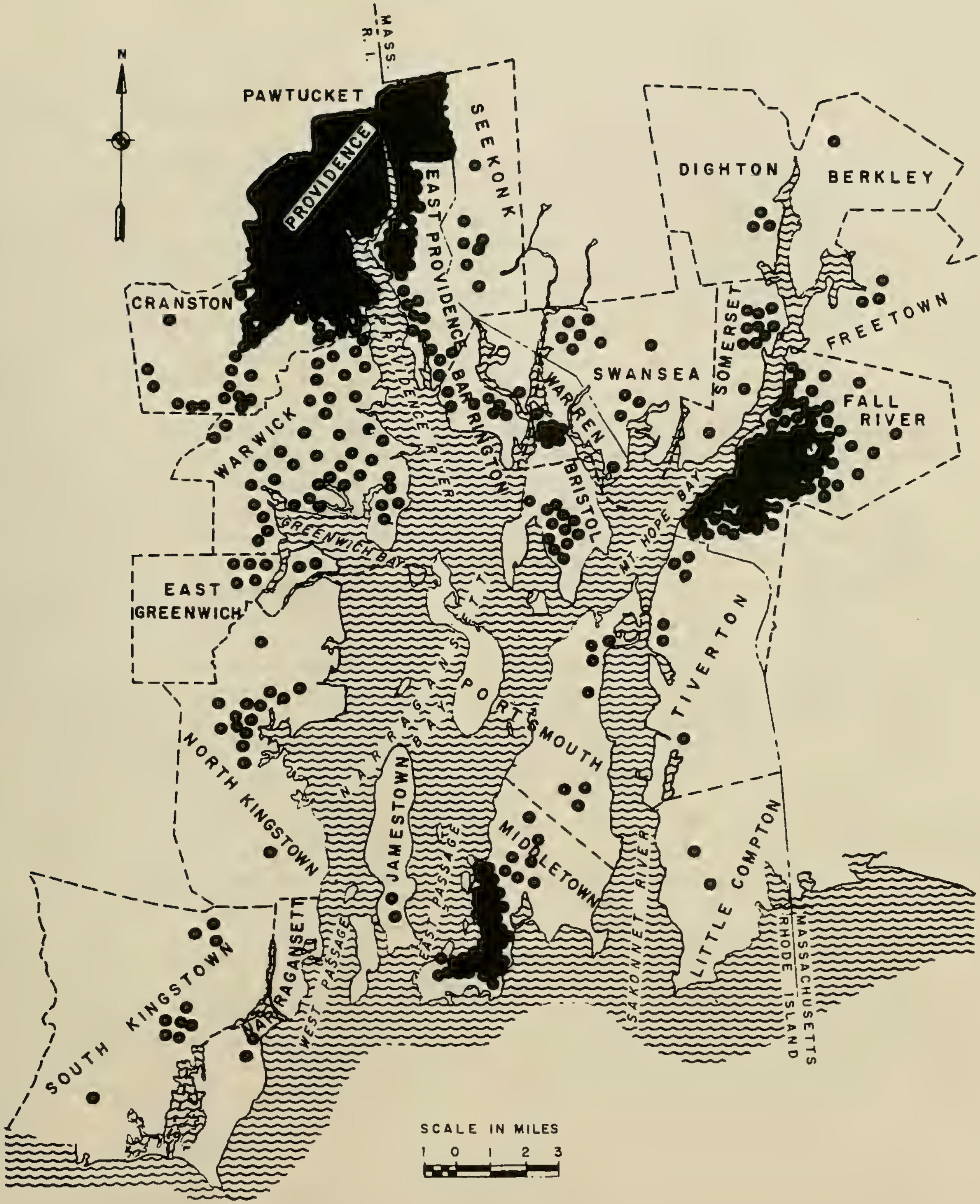
City or Town	Population
Jamestown, R.I.	2,068
Little Compton, R.I.	1,556
Berkley, Mass.	1,284

14. INDUSTRY

Most of the major industrial areas of Rhode Island and the industrial city of Fall River, Massachusetts, are located in the Narragansett Bay area. The employed labor force numbers approximately 196,200, of whom 63 percent are engaged in manufacturing, in contrast with the United States average of 25 percent. The economy of the area is centered around three major industries, textiles, metal trades and jewelry, constituting 80 percent of the manufacturing employment and 51 percent of the total employment of the area. Providence and Fall River are the chief manufacturing cities. Providence alone accounts for 47 percent of the metal trades and 91 percent of the jewelry-silverware industry. Fall River accounts for 50 percent of the textile and apparel industry of the area.

15. FISHERIES

Fishing is one of Rhode Island's oldest industries, dating back to early colonial times. Today, the value of the annual commercial catch of finfish and shellfish is about $5,000,000; this amount may vary somewhat from year to year. In 1955, more than $4,600,000 worth of finfish and shellfish were landed at Rhode Island ports, an increase of 11 percent over 1954. The commercial finfish include both foodfish and "trash" fish, the latter used to produce animal feeds, glue fertilizer and other products. Flounder, herring, butterfish and scup are the principal varieties of commercial foodfish. The hard clam (quahog) fishery is of considerable importance, its value amounting to about $2,000,000 annually. Other shellfish species of somewhat less commercial importance are bay scallops, soft clams, oysters and lobsters. The estimated annual expenditure for marine sport fishing is more than $3,000,000. The principal sport fish species are striped bass, bluefish and tautog.



LEGEND

● = *1000 Population*

HURRICANE SURVEY
NARRAGANSETT BAY
RHODE ISLAND-MASS.
POPULATION DISTRIBUTION
CORPS OF ENGINEERS U.S. ARMY
NEW ENGLAND DIVISION
BOSTON, MASS. DEC. 1956

FIGURE 1

16. AGRICULTURE

Agriculture holds a relatively unimportant position in the economy of the area. Although the land of the state of Rhode Island is fertile, only 1.5 percent of the labor force of the state is engaged in farming as a primary employment, and this percentage is decreasing as urban development expands into farming areas. In the less industrialized areas, however, particularly along the Middle and Lower Bays, there are a number of thriving farms.

17. NAVIGATION

Narragansett Bay, one of the deep water harbors on the Atlantic coast, is the seaway to the ports of Providence and Fall River, which rank third and fifth, respectively, in commercial tonnage in New England. The total annual tonnage passing through the bay is about 10,000,000 tons, of which about 75 percent is destined for the port of Providence. Three distinct types of vessels comprise the traffic in the bay, - deep-draft commercial vessels, Naval vessels, and small fishing and recreational craft.

The deep-draft commercial vessels carry cargo consisting principally of imports of petroleum and petroleum products, and of coal. In 1955, these commodities accounted, respectively, for 85 percent and 10 percent by weight of the total cargoes received at Providence. In 1955, annual commercial vessel traffic passing through the bay totaled about 370 vessel trips a year for vessels having drafts of 30 feet or greater and about 230 vessel trips for vessels having drafts between 25 and 30 feet. Commercial vessels having drafts of less than 25 feet made approximately 25,000 vessel trips to and from the various ports within the bay.

Naval vessels using the bay include all types of modern fighting ships, which are part of the Atlantic Fleet (see paragraph 20). Thousands of small fishing and recreational craft navigate the waters of the bay in connection with commercial and sport fishing and sailing and motor boating. In recent years, the number of pleasure craft, both sailboats and motorboats, has increased spectacularly.

18. TRANSPORTATION

The area, containing the second largest metropolitan region in New England, is served by an extensive system of highways, railroads and airlines. Major highways radiate from Providence connecting the area with Boston, Worcester, Hartford, New London and New Bedford.

U. S. Route 1 from Boston passes through Providence and then follows the westerly shore of Narragansett Bay for nearly its entire length. The chief east-west highway is U. S. Route 6, connecting Providence with Hartford, Fall River and the Cape Cod area. State Route No. 114 serves Newport and other communities along the easterly shore.

The main line of the New York, New Haven and Hartford Railroad from Boston to New York provides daily passenger and freight service for the Providence area. Branch lines serve Fall River and Newport. The Theodore Francis Green Airport in Warwick, about 7.5 miles south of the center of Providence, is the center of commercial aviation. Major airlines provide regularly scheduled flights to all parts of the United States.

19. RECREATION

Narragansett Bay has long been famous as a recreation and vacation center. Newport is one of the oldest resorts in the United States. Other famous resorts are Jamestown and Narragansett. With more than 250 miles of coastline, Narragansett Bay naturally features salt-water sports. Bathing is enjoyed from early summer until late September at public and private beaches. Striped bass, bluefish and tautog are popular attractions for sports fishermen. A large number of yacht clubs and boat yards maintain facilities for small boats and fishing craft. In the summer there are frequent yacht races, including such national events as the Newport to Bermuda and Newport to Annapolis races.

20. DEFENSE ESTABLISHMENTS

Within the Lower and Middle Bays is one of the primary Naval bases of the United States. The waters provide a natural land-locked, deep-water, ice-free harbor for the largest ships of the Navy. A complex of docks, repair yards, berthing areas, airfields and training schools occupies large stretches of the coast, particularly in Newport, North Kingstown and Portsmouth. Among the more important establishments are the Newport Naval Base; the Naval War College and the Naval Underwater Ordnance Station, both in Newport; the Naval Air Station at Quonset Point in North Kingstown; the Naval Construction Battalion Center at Davisville in North Kingstown; and the Naval Net Depot in Portsmouth.

21. CLIMATE

The temperate and changeable climate of the bay area is marked by four distinct seasons which are characteristic of the latitude and of New England. Owing to the moderating influence of the bay and nearby ocean waters and particularly to the variable movements of high- and low-pressure areas associated with continually changing weather patterns, extremes of either hot or cold weather are rarely long lasting. In the winter, coastal storms frequently bring rainfall, in contrast with snow in interior areas. In the summer, cooling relief from hot, humid weather is provided by sea breezes from the east and southeast, thunder storms from the west, and cool air from the north. The prevailing winds are northwesterly in winter and southwesterly in summer. High winds, heavy rainfall and abnormally high tides occur frequently in the hurricane months of August, September and October.

22. TEMPERATURE

The mean annual temperature of the area is approximately 50°F. February, the coldest month, has a mean temperature of 29°F, and July, the warmest month, has a mean temperature of 73°F. Freezing temperatures, which are common from late November through March, occur on an average of 105 to 110 days a year. The lowest temperature recorded in Providence was -17°F on February 9, 1934, and the highest temperature was 102°F on August 26, 1948.

23. PRECIPITATION

The average annual precipitation is about 45 inches and is rather evenly distributed throughout the year. Measurable precipitation occurs on an average in about one day out of three. The average annual rainfall at Providence, since the establishment of the Providence office of the U. S. Weather Bureau in 1904 is slightly greater than 39 inches. The heaviest precipitation recorded at Providence for a 24-hour period was 6.17 inches on September 16, 1932. Winter snowfall in Providence averages 34 inches. A minimum of 11.8 inches was recorded during the winter of 1936-1937 and a maximum of 75.6 inches during the winter of 1947-1948.

Further information on climatology will be found in Appendix C.

HURRICANE TIDAL FLOODS OF RECORD

24. HISTORICAL HURRICANES

Narragansett Bay, with its axis north and south and its mouth open to the Atlantic Ocean, lies in the path of the great hurricanes which approach the New England coast. Since 1620, there have been recorded 25 damaging hurricanes and 38 hurricanes that narrowly missed the area without inflicting important flood damage.

Records indicate that during the period from 1635 to 1900 hurricane flooding of damaging proportions occurred nine times, in August 1635, August 1638, October 1723, October 1761, September 1815, October 1866, September 1869, October 1878 and December 1878. Detailed data on hurricanes producing tidal flooding along the southern New England coast are given in Appendix A.

The earliest hurricanes recorded in New England, including the Narragansett Bay area, appear in Governor William Bradford's "History of Plymouth Plantations, 1620 - 1647," and in Governor John Winthrop's "History of New England," which describe violent storms in 1635 and 1638 that created flood levels apparently higher than the recent floods of 1938 and 1954. Referring to the hurricane of August 1635, Governor Winthrop wrote: "The tide rose at Narragansett fourteen feet higher than ordinary and drowned 8 Indians flying from their wigwams." Of the storm of August 1638, Governor Winthrop wrote: "It flowed twice in 6 hours and about Narragansett Bay it raised the tide 14 or 15 feet above the ordinary spring tide, upright."

During the Great Gale of September 23, 1815, the flood waters rose to a height of 14.2 feet above mean sea level or 11.8 feet above mean high water at Providence.

25. RECENT HURRICANES

Very early accounts of hurricanes in the area are brief, but since 1815, and particularly in the last 50 years, accounts have become increasingly more complete because of the growing number of trained observers and rapid advances in the knowledge of meteorological phenomena. The contemporary period from 1901 to the present is marked by fairly complete and scientific accounts of hurricanes.

HURRICANE SURVEY
NARRAGANSETT BAY
RHODE ISLAND

PATHS OF TROPICAL STORMS
OF
HURRICANE INTENSITY

CORPS OF ENGINEERS, U.S. ARMY
NEW ENGLAND DIVISION
BOSTON, MASS. DEC 1956

FIGURE 2

The three most damaging hurricanes since 1900 occurred in the 17 year period between 1938 and 1954. Two of these, the hurricanes of September 1938 and August 1954 (Carol), produced flood levels of 15 to 16 feet above mean sea level at Providence. Both hurricanes were nearly coincident with gravitational high tide, which contributed significantly to the severity of the flooding. The hurricane of September 1944 although a severe storm, struck at a time of low tide and flooding was consequently less severe.

26. HURRICANE FREQUENCY

The distribution of recorded hurricane occurrences in the Narragansett Bay area by estimated degree of intensity is shown in Table 2. The fact that there is a record of 39 hurricane occurrences in the first 55 years of the 20th century (1901-1955), as compared with 24 occurrences in the 266-year period between 1635 and 1900 is attributed to the lack of records on early storms and is not believed to be indicative of any trend toward greater frequency of occurrence in recent times.

TABLE 2

HURRICANE OCCURRENCES,
NARRAGANSETT BAY AREA

Century / Intensity	17th 1635-1700	18th 1701-1800	19th 1801-1900	20th 1901-1955	Total
Major Tidal Flooding	2	2	5	3	12
Moderate Tidal Flooding	No Record	1	5	7	13
Threatened Area, Path near R.I. Coast	No Record	3	6	29	38
Totals	2	6	16	39	63

As indicated by recorded facts, the Narragansett Bay area has experienced severe hurricane tidal flooding upon eight occasions from 1815 to 1955, or an average of one occurrence in 20 years. However, reliable information on hurricane high-water marks is available only for the three recent hurricanes of 1938, 1944 and 1954. There are no detailed data on the tidal-flood levels attained

in the five great hurricanes of the 19th century. Descriptive material of a general nature indicates that the levels of flooding in these five storms probably did not exceed the levels experienced in 1938 and 1954. Using the three recorded high-water marks attained in recent hurricanes and the estimated flood levels in five hurricane occurrences during the 19th century, an elevation-frequency curve has been prepared. In preparing the curve, account has been taken of the historical hurricanes of 1635 and 1638, their frequency being established on the basis of the period from 1635 to 1955 and their elevations of flooding being assumed as higher than the 1938 flood level.

With respect to seasonal variation of hurricane occurrences in southern New England, the period of greatest activity extends from early August to the end of October. However, records indicate occurrences as early as the middle of June and as late as the middle of December.

HURRICANE CHARACTERISTICS

27. GENERAL DESCRIPTION

The term "hurricane" is applied to an intense cyclonic storm originating in tropical or subtropical latitudes (between 5° and 20°) in the Atlantic Ocean north of the Equator. Accumulation of heat close to the surface of the water provides energy for water vaporization and the movement of masses of moist tropical air. A hurricane is characterized by low barometric pressures, high winds (75 miles per hour or greater), heavy clouds, torrential rain, tremendous waves and tidal surges.

28. ORIGINS AND TRACKS

Most hurricanes that have affected the eastern coast of the United States have formed either near the Cape Verde Islands or in the western Caribbean Sea. Hurricanes originating near the Cape Verde Islands move westward for a number of days with a forward speed of about 10 miles an hour, then usually turn north, frequently crossing the West Indies and sometimes striking the eastern coast of the United States. Hurricanes originating in the Caribbean generally move northward, striking Cuba, the Gulf Coast or the eastern coast of the United States. After recurvature, the forward speed usually increases to 25 to 30 miles an hour, occasionally to 60 miles an hour. Cape Verde hurricanes commonly recurve (turn northward then east of north) any time after reaching the mid-Atlantic. Hurricanes that affect New England most severely usually arrive from the south-southwest after recurvature east of Florida and after skirting the Middle Atlantic coast.

29. WINDS AND BAROMETRIC PRESSURE

The highest winds of a hurricane are those within a circular region extending from the edge of the "eye", or calm center, outward for 10 to 15 miles. The diameter of the eye is usually about 15 miles, although the eye of a mature hurricane is frequently 20 to 30 miles in diameter. Wind movement is not directly toward the low pressure cyclone center or eye of the hurricane but approaches the center in a counter-clockwise spiral. Consequently, the highest wind velocities occur at points to the right of the center of the hurricane where the spiral wind movement and the movement due to forward motion of the center are in the same direction. Since destruction by the wind is greatest in the area on the right side of the hurricane, this area is known as the "dangerous semicircle".

Atmospheric pressure falls rapidly as the center of the hurricane approaches and as the velocity of the wind increases. Minimum barometric readings do not always occur in the center of the eye. In some instances, the minimum is reached at the beginning of the calm period while in others the minimum is reached at the end of the calm period. Usually the barometric low is about two inches below the normal sea level pressure of 30 inches. However, in several hurricanes pressures of as much as three inches below normal have been recorded. In the United States, the lowest barometric pressure ever recorded was 26.35 inches at the northern end of Long Key, Florida, on September 2, 1935.

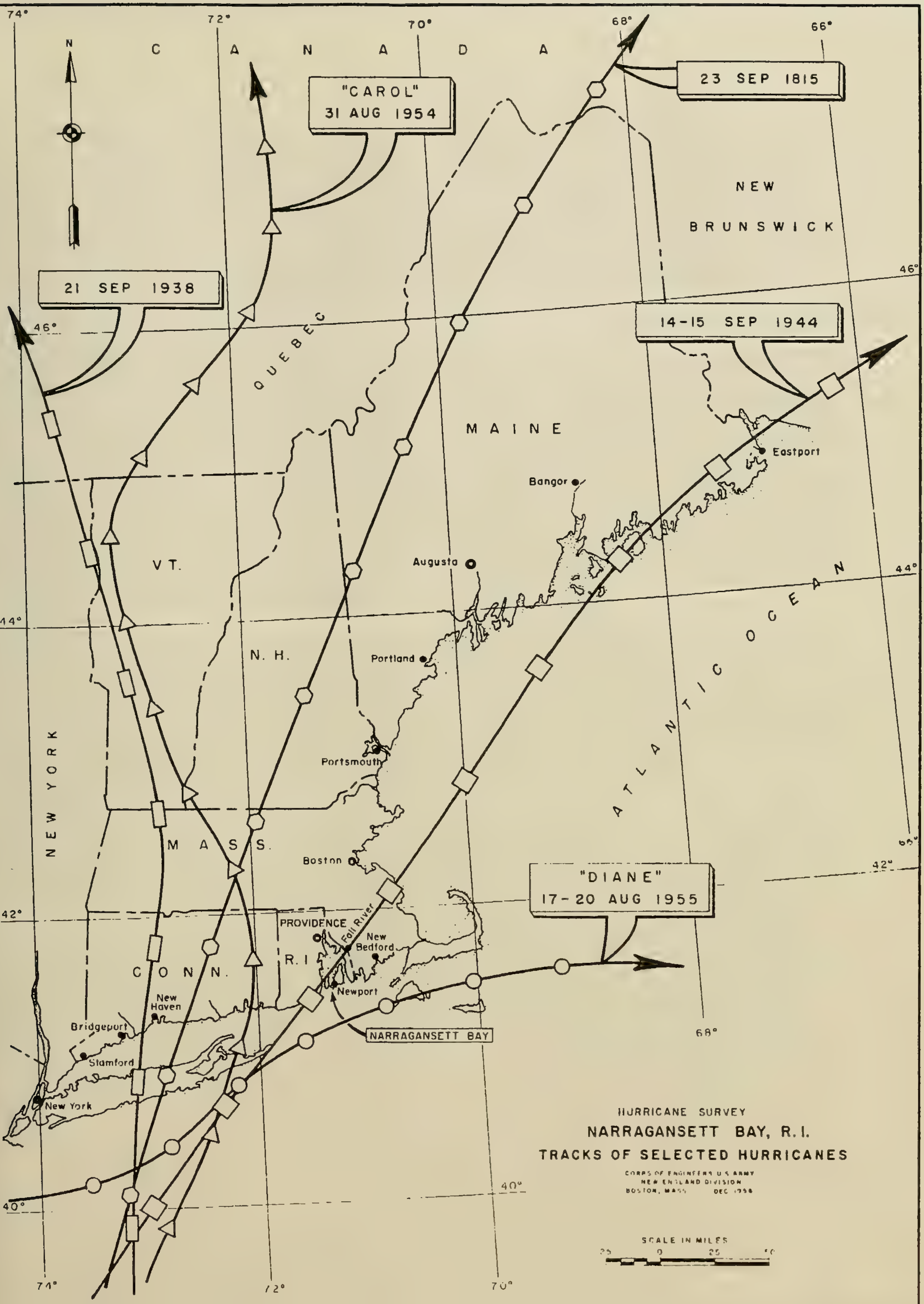
30. RAINFALL

Another characteristic of a hurricane is the heavy rainfall that usually accompanies the storm. At the edge of the disturbance rainfall is light, normally in the form of showers. As the center approaches, the showers increase in frequency and intensity, becoming heavy to excessive near the eye. The heaviest rain usually falls ahead of the eye, driving torrentially from spiral bands of clouds that sometimes produce nearly two inches of rain per hour. For a 24-hour period, amounts exceeding 20 inches are not uncommon. Record rainfall near the Narragansett Bay area occurred during Hurricane Diane (August 1955) when 18.15 inches of rain fell at Westfield, Massachusetts, on the 18th.

31. WAVES

Much of the hurricane damage is caused by waves generated by hurricane winds. Vessels at sea suffer greatly in the northeast quadrant of the hurricane and in the confused seas of the storm center where waves 45 feet or more in height have been reported. These mountainous waves appear in wild pyramidal masses and the magnitude of their destructive power is revealed only in the appalling record of lives lost and ships sunk at sea or wrecked on shoals and shores. Such giant ocean waves will traverse tremendous distances while diminishing in size and strength, reaching distant shores one or two days in advance of the hurricane and causing damage even before the onset and release of the fury contained in the storm proper.

In the deep water of the open ocean, the height, period and velocity of many of the waves produced are a function of the wind velocity. The ultimate size of the waves depends upon the force and duration of the wind and the fetch or distance the wave travels. As ocean waves come into shoal waters, their forward movement is slowed by friction on the bottom, and they rise to a new height



C A N A D A
N
"CAROL"
31 AUG 1954
23 SEP 1815
21 SEP 1938
14-15 SEP 1944
NEW
BRUNSWICK
QUEBEC
MAINE
Eastport
Bangor
Augusta
VT.
N. H.
Portland
NEW YORK
Portsmouth
ATLANTIC OCEAN
M A S S.
Boston
"DIANE"
17-20 AUG 1955
PROVIDENCE
Fall River
New Bedford
R. I.
C O N N.
Newport
New Haven
Bridgeport
Stamford
NARRAGANSETT BAY
New York
HURRICANE SURVEY
NARRAGANSETT BAY, R.I.
TRACKS OF SELECTED HURRICANES
SCALE IN MILES
0
25

FIGURE 3

before they are dissipated in shoal waters or break on the shore. Driven by hurricane winds, the breaking waves will run up on a shelving beach or overtop vertical structures well above the wave heights, so that reports of wave and flood damage from 5 to 25 feet above water level are not uncommon. Hurricane waves do great damage to shorefront land and buildings and to vessels and small craft. In the hurricane of 1938, the waves within Narragansett Bay carried a number of lighthouses off foundations which were well above normal water levels.

32. TIDAL SURGES

Although hurricane winds have caused the deaths of thousands, and thousands more have lost their life in ships destroyed at sea, most of the losses of human life and property in hurricanes are due to flooding. Flooding, one of the most devastating effects of a hurricane, results from movement of the storm surge, or substantial rise in water levels, onto a shoaling coast and into a bay or inlet. The surge is caused by a combination of hurricane winds and low barometric pressure in a storm having a track and speed of forward movement synchronized with the normal pattern of tidal movement and oscillations of the sea in the open ocean.

Usually the rise of the sea is gradual as the center of the storm approaches but sometimes it comes with great swiftness. Rising waters accompanying hurricanes have been called "tidal waves", although they are not tides in the ordinary sense. The history of terrible storms reveals many instances of cities and towns flooded, with thousands of lives lost, evidence that such rises are not always gradual.

Usually the level of the storm surge is increased by a rising ocean bed and favorable shore contours, factors which similarly affect the astronomical tide in shore locations. The ordinary rise of the tide amounts to only one or two feet in the open oceans, while its range is often ten to twelve feet at coastal points. In certain bays and channels the rise is 25 to 50 feet above low water. The times of ebb and flow of such tides are, of course, well known, but the storm surge comes so rarely to any one community that it is seldom anticipated in its fully developed form. A well-defined storm surge is not developed unless the slope of the ocean bed and contour of the coastline are favorable to its rise, in combination with the proper direction of the storm track and speed of movement.

In the open ocean the rise due to the storm surge seldom exceeds 3 feet, but it increases considerably on the continental shelf and along the coastline where it builds up in height, in much the same way that a ground swell builds up in shoal water. An additional rise in level occurs due to the effect of hurricane winds blowing over shoaling coastal waters and shallow bays and inlets, depending on the fetch, the depth of the water, and the wind intensity and duration. The rises in level from the combination of offshore surge and local wind effects may range from 6 to 8 feet above normal high tide on the coast, and to 12 or 14 feet above normal high tide in bays and inlets.

DESIGN HURRICANE TIDAL FLOOD

33. ANALYSIS OF THE HURRICANE SURGE

As a hurricane progresses over the open water of the ocean, a tidal surge is built up, not only by the force of the wind and the forward movement of the storm wind field, but also by differences in atmospheric pressure accompanying the storm. This surge is further increased as the storm approaches land over a gradually shoaling ocean bed and is influenced considerably by the contours of the coastline. An additional rise results when the tidal surge invades a bay or estuary and hurricane winds drive waters to higher levels in the shallow waters. Tidal surges are greater and the tidal flooding more severe in coastal communities which lie to the right of the storm path, due to the counter-clockwise spiraling of the hurricane winds and the forward movement of the storm. The actual height reached by a hurricane tidal surge and the consequent damages incurred depend on many complicated factors.

34. WIND FIELD AND BAROMETRIC PRESSURE

The maximum gust of wind recorded in any hurricane in New England is 186 miles per hour; a sustained 5-minute velocity of 121 miles per hour was recorded in the September 1938 hurricane at the Blue Hill Observatory, Milton, Massachusetts, about 30 miles north of Providence. At Providence, the maximum recorded 1-minute sustained wind velocity was 95 miles per hour, with a 5-minute sustained blow of 87 miles per hour and maximum estimated gust of 125 miles per hour, in 1938. During the hurricane of September 1944, the maximum gust in New England was 104 miles per hour at Chatham, Massachusetts, about 45 miles east of New Bedford. Peak gusts measured during Hurricane Carol (August

Wave action at Bristol, Rhode Island during Hurricane "Carol" (August 1954). Street is 21 feet above mean high water.

Photo submitted by Bristol Harbor Development Commission

1954) were 142 miles per hour at Mount Washington in New Hampshire (170 miles north of Providence), 130 miles per hour at Block Island, Rhode Island (45 miles southwest of Providence), 125 miles per hour at the Blue Hill Observatory and 105 miles per hour at the Theodore Francis Green Airport in Warwick, Rhode Island, (7.5 miles south of the center of Providence).

The diameter of the low-pressure area in the center of hurricane storms has measured as much as 30 miles but usually ranges from 10 to 15 miles. The lowest barometric pressure ever recorded in the Western Hemisphere was 26.35 inches in the Florida Keys during the hurricane of 1935. The minimum in New England was 28.04 inches recorded at Hartford, Connecticut, during the 1938 hurricane. The minimum at Providence was 28.51 inches in the September 1944 hurricane; the lowest pressure recorded in New England during this storm was 28.30 inches at Westerly, Rhode Island. In Hurricane Carol (August 1954), 28.20 inches was recorded at Storrs, Connecticut, and 28.79 inches at Providence. Further data on wind velocities and barometric pressures in past hurricanes are included in Appendix B.

35. ASTRONOMICAL TIDE AND TIDAL FLOODING

An important factor influencing the height of the hurricane surge is the stage of the normal tide at the time the surge arrives at the coast. The September 1938 hurricane tide reached Narragansett Bay approximately concurrent with the predicted high tide, whereas the August 1954 hurricane tide occurred about two hours after the predicted high tide. The September 1938 surge elevation at Providence was 15.7 feet above mean sea level and the August 1954 elevation was 14.7 feet above mean sea level, but the difference between predicted tide height and surge height was 13.3 feet in 1954 and 12.6 feet in 1938. Thus the 1954 flood would have been about two feet higher and about 0.7 foot above the 1938 flood level had it occurred at the time of high tide.

The September 1944 hurricane tide arrived at Providence about one hour before the predicted low tide and therefore did not produce major flooding. It reached an elevation of only 9.9 feet above mean sea level at Providence although the rise above predicted tide elevation was 11.6 feet.

In determining future tidal flood levels, one factor to be considered is the rise in mean sea level that is taking place along the New England coast. Continuing investigations being made by the U. S. Coast and Geodetic Survey in regard to changes in sea level indicate that mean sea level has risen at a rate of approximately 0.02 foot

per year since 1930 (see report by the Council on Wave Research in Proceedings of the First and Second Conferences on Coastal Engineering, 1952). If this trend continues and storms of the magnitude of the 1938 and 1954 hurricanes were to occur at the end of the next 50 years, flood levels would be approximately one foot higher than were actually experienced in these storms. The effect of rising sea level is to increase the severity of future hurricane tidal flooding.

36. STORM TRACKS

Each of the three great recent hurricanes namely those of 1938, 1944 and 1954 followed a path from 20 to 80 miles west of Narragansett Bay, thereby placing the bay in the sector of the strongest and most damaging hurricane winds and in the sector where the storm surge is highest. Figures 2 and 3 show these storm tracks.

37. SELECTION OF DESIGN HURRICANE TIDAL FLOOD

In the design of protective works, structures must be built of sufficient height and strength to withstand the most severe combination of storm tide and wave action that can reasonably be expected. A "design hurricane" for use in determining the required height of protective structures has been established through the joint cooperation of the U. S. Weather Bureau and the Beach Erosion Board, assisted by the Texas A & M Research Foundation. The basis of the design storm is a transposition of the 1944 hurricane because this storm when it was off Cape Hatteras, had the greatest amount of energy of any recorded storm along the Atlantic Coast. However, the 1944 hurricane when it struck New England was not nearly so serious as either the 1938 or 1954 hurricanes because (1) its energy had been partly dissipated over the land north of Cape Hatteras, and (2) it struck at a time of low tide. In deriving the design hurricane, the 1944 storm was transposed so that it would be over water between Cape Hatteras and the New England coast, resulting in less drop in barometric pressure at the center of the storm than actually occurred in 1944. The transposed hurricane, having the intensity of the 1944 hurricane off Cape Hatteras, was assumed to move with a forward speed of 40 knots (about 46 miles per hour) in a northerly direction and to pass over New England with its center 49 nautical miles west of Providence. This would place Narragansett Bay in the most critical area of the storm. Wind velocities were ascertained by the U. S. Weather Bureau for the passage of the storm, and a velocity of 76 miles per hour, the sustained wind velocity over most of the Narragansett Bay area, was selected as the design-storm velocity. The storm-tide potential at the entrance to Narragansett Bay was determined, including a preliminary estimate of the height of the surge after its propagation along the coast and up Block Island Sound to the entrance of Narragansett Bay.

38. DESIGN HURRICANE FLOOD LEVELS

The computation of storm-tide potentials, including a description of the method used, is contained in a report dated March 1956, "Dynamic Storm-Tide Potentials," prepared by the Department of Oceanography of the Texas A & M Research Foundation in connection with research for the Beach Erosion Board. In accordance with procedures outlined in this report, the 1944 design hurricane storm-tide potential off Newport Harbor at the entrance to Narragansett Bay was calculated to be 12.8 feet above mean sea level or approximately two feet above the level of the 1938 hurricane. By a combination of analytical methods and model tests, the level was determined to be 18.7 feet above mean sea level at Providence or about three feet above the actual 1938 flood elevation. The full development of the design hurricane is given in Appendix B.

39. DESIGN WAVES AND WAVE RUN-UP

Wave heights with the design wind velocity of 76 miles per hour are estimated to be 25 feet from crest to trough at the entrance to the bay and from 6 feet to 9 feet within the bay depending on the fetch and depth of water (see Table 3). These are "significant" wave heights and would be exceeded by individual waves by as much as 60 percent.

The amount of wave run-up (the height above still-water level reached by the rush of water up a structure on the breaking of a wave) on the seaward side of protective works would exceed the wave heights shown in Table 3.

40. STREAM FLOW COINCIDENT WITH HURRICANE TIDAL FLOODING

Heavy rainfall is normally associated with great hurricanes. Warm, moisture-laden air is carried in over the land from the ocean by northeasterly winds in advance of a hurricane causing heavy precipitation before and at the time the hurricane strikes. Consequently, high river runoff and severe flooding are likely to occur at the same time as a hurricane tidal flood. An example of this situation was provided by the hurricane flood of September 1938 when many of the rivers in New England overflowed their banks and caused extreme flood losses one day in advance of the hurricane, while on other rivers, such as the Thames River above New London, Connecticut, fresh-water flooding occurred two hours before salt-water flooding. See Appendix C for a detailed discussion of stream flow.

TABLE 3

DESIGN WAVE HEIGHTS
NARRAGANSETT BAY

	Significant Wave Height (ft.)	Period (sec.)	Run-Up (ft.)	
Lower Bay Barriers				
East Barrier				
South Side	25	11	31	(Stone Breakwater)
North Side	6	5	7.5	" "
West Barrier				
South Side	20	11	25	" "
North Side	7	5	9	" "
Tiverton Barrier				
South Side	9	7	11	" "
North Side	4	3.5	5	" "
Fox Point Barrier				
South Side	6	5	6	(Vertical Concrete Wall)
North Side	2	2.5	2.5	" "

41. DESIGN STREAM FLOW

Of the great storm rainfalls recorded in New England, only the September 1938, September 1944 and August 1954 (Carol) rainfalls were associated with major hurricane storm tides. Since the September 1938 storm had the greatest rainfall of record associated with hurricane winds and the highest recorded tide levels, it was adopted for design studies. The storm rainfall, which was centered

over Buck, Connecticut, was transposed to the area in Narragansett Bay above the investigated tidal barriers. For studies of the area above Fox Point in Providence, the 24-hour storm rainfall of 9.5 inches was centered over the Woonasquatucket and Moshassuck River Basins, and for studies of other areas the 72-hour storm rainfall of 14.2 inches was centered over the Blackstone River Basin.

EXTENT AND CHARACTER OF THE FLOOD AREA

42. The hurricane of August 1954 (Carol) caused destructive tidal flooding along most of the 250-mile shoreline of the Narragansett Bay area between Point Judith on the west and Sakonnet Point on the east. Flood levels ranged from 9.8 feet above mean sea level at Newport to 14.7 feet above mean sea level at Providence. Flood levels in the hurricane of September 1938 were higher by one foot. Some 20,500 acres in the States of Rhode Island and Massachusetts were inundated in each of the two floods. The 1938 flood took more than 250 lives in Rhode Island alone. In the 1954 hurricane 19 lives were lost in Rhode Island, the majority by drowning in the flooded areas of Narragansett Bay and the south shore.

By far the principal flood damage center is the city of Providence, where about one-third of the area's population of more than 725,000 reside. In the 1954 flood, about 500 acres of the commercial and industrial center of Providence was inundated and damages amounted to aproximately one-third of the total flood damages sustained (see paragraph 43). The remaining two-thirds of the damages are distributed around the eastern and western shorelines of the bay and in the Massachusetts communities bordering Mount Hope Bay. The larger Rhode Island suburban and residential communities on the shorelines are Cranston, Warwick, Warren and Bristol in the Upper Bay and Newport in the Lower Bay. Fall River, Massachusetts is the largest community on Mount Hope Bay.

The shorefront has been extensively developed for recreational purposes. In the Lower Bay, where major U. S. Naval installations are located, losses to Naval property have been heavy. For a fuller discussion of the extent and character of the flood area, see Appendix D.

Flood waters of Hurricane "Carol" (August 1954) receding from center of business district in Providence. Waters rose as high as eight feet at peak of flood.

Photo by Dennis A. Murphy

43. EXPERIENCED DAMAGES

Hurricane Carol of August 1954 left in its wake a total flood loss of about $92,000,000 in the Narragansett Bay area. Almost 80 percent of this loss was sustained by residential, commercial and public property, including U.S. Naval property. The remainder was sustained by industrial, rural, highway and railroad property, and public utilities. See Appendix D for a detailed discussion and tabulation of damages. The city of Providence suffered far greater damage than any other locality caught in the path of Hurricane Carol. Losses in the city amounted to more than $41,000,000. The heart of the business section was inundated by 4 to 8 feet of polluted salt water. Hundreds of commercial establishments suffered heavy losses, including in many instances a total loss of stock and equipment. Industrial losses in the city amounted to over $6,700,000.

Along the western shoreline of the bay south of Providence, from Cranston to Point Judith, tidal flood damages amounted to almost $28,000,000. Two areas particularly hard hit on the west side were Warwick and North Kingstown. Tidal flood losses on the east side of the bay were almost as high as those on the west; in the area extending from East Providence to Sakonnet Point, including the Mount Hope Bay area, damages totaled more than $23,000,000.

Flood damages in the hurricane of 1938 were even greater than in Hurricane Carol. Although no accurate evaluation of experienced 1938 damages is available, it is estimated that a recurrence of the 1938 flood stages at price levels prevailing in 1956 would cause losses of about $120,000,000, of which nearly $8,000,000 would be incurred within the Massachusetts portion of the Narragansett Bay area, as shown in Plate 2.

In addition to the evaluated losses in the Narragansett Bay area, there are categories of losses which were not included or included only in part, because loss information in usable form was meagre or unavailable. Available evidence indicated, however, that these losses were substantial in the tidal flooding of 1938 and 1954. These categories consist of (1) tangible losses to non-fixed or transient items such as craft afloat and vehicles parked on streets or in parking lots; (2) tangible losses outside the immediate flood area; and (3) intangible losses such as loss of life, health, security, and detrimental effects upon national defense, which are either indeterminate or monetarily unmeasurable.

44. RECURRING DAMAGES

Estimates have been made of the damages for flood stages equivalent to those of the 1938, 1944, 1954 and design hurricanes and for other recent hurricanes and severe storms based on stage-damage relationships obtained from the damage surveys. These recurring losses are summarized in Table 8 at 1956 price levels. In the development of recurring losses allowances have been made for (1) the anticipated effectiveness of individual plant flood protection, (2) the recovery of loss potential at property completely destroyed, (3) a general change in price levels due to increased costs, and (4) the estimated economic growth of the area.

45. AVERAGE ANNUAL LOSSES

Average annual tidal flood losses in the Narragansett Bay area have been estimated at $5,922,000 at 1956 price levels. These losses were derived by correlating stage-damage, stage-frequency and damage-frequency curves in accordance with standard practice. A stage-frequency curve, based upon the known peak elevations of recent hurricanes and high water and peak elevations estimated from historical data of flood-producing storms of the past 321 years, was correlated with stage-damage relationships, referenced to the 1954 hurricane tidal-flood crest, to arrive at damage-frequency curves, as described in Appendix D.

In view of the lack of precedent for estimating annual losses due to tidal flooding, an alternative method of estimating annual losses was used for comparison, based upon the assumption of a recurrence within the next 50 years, under economic conditions existing in 1956, of the hurricanes of 1938, 1944, and 1954, and 22 flood-producing storms. A recurrence of the flood stages of these hurricanes and storms within the next 50 years in the protected area would cause an estimated total loss of $227,200,000, or an average annual loss of $4,544,000 in the 50-year period. The annual loss derived by this method is comparable to that derived by the frequency method.

46. SCARE COSTS

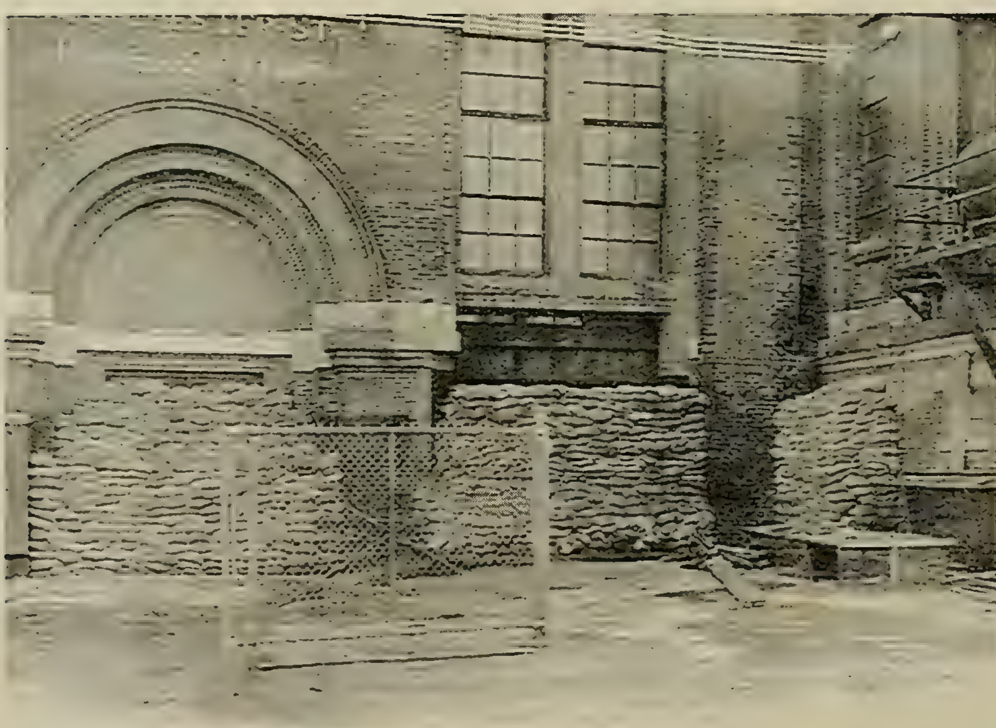
In addition to damages from tidal flooding, losses are incurred in the flood area by the institution of temporary preventive measures upon advice of hurricane warnings, whether flooding occurs or not. Scare costs of a single hurricane warning are estimated at $325,000. Based on a frequency of three hurricane warnings in a 10-year period, average annual scare costs amount to $98,000. Appendix D discusses in detail the derivation of recurring losses, annual losses and scare costs.

Flood damage at Conimicut Point, Warwick, Rhode Island. Hurricane of September 1938. Similar destruction occurred during Hurricane "Carol" (August 1954) when more than 60 homes were destroyed and many others seriously damaged.

Photo by Providence Journal Co.

Wreckage left in Providence by subsiding flood waters of Hurricane "Carol" (August 1954).

Photo by C. Demerjien



Sandbagging of entrances to an electric generating station. In addition to actual flood damages, losses are sustained due to temporary preventive measures taken during a hurricane "Scare".

Photo by E. F. Walsh

EXISTING CORPS OF ENGINEERS' PROJECTS

47. There are no existing or authorized hurricane protection projects in the Narragansett Bay area. Twelve projects for the improvement of navigation have been authorized of which eight have been completed. In addition, there are six authorized navigation surveys and four authorized preliminary examinations for navigation. Although these projects would have no effect on hurricane-induced tidal flooding, the projects which include breakwaters would reduce wave action. The projects would also have some influence on the selection of sites for, and the design of, proposed protective structures. In addition to navigation projects in the area, there are four authorized flood control projects on the Blackstone River, two of which, the local protection at Woonsocket, Rhode Island, and the Worcester Diversion project, are under construction. The others include a local protection project at Pawtucket, Rhode Island; and a flood control reservoir at West Hill, Massachusetts. Only the reservoir project would affect the runoff from the Blackstone River. None of the others would reduce flood flows entering Narragansett Bay from tributary rivers during heavy rainfalls accompanying hurricanes and so would not affect the design of hurricane protection structures.

IMPROVEMENTS DESIRED

48. VIEWS OF LOCAL INTERESTS

The three hurricanes of 1954, - Hurricane Carol (August 31), Hurricane Edna (September 11) and Hurricane Hazel (October 15), following so closely on the disastrous flooding of 1938, served as powerful stimulants to local interests to seek positive means of protection against hurricane tidal flooding. The danger resulting from recurring hurricanes was clearly recognized as a grave threat to the economy and growth of the area. Citizens' groups, municipal officials and representatives of the State of Rhode Island earnestly pressed for quick action on legislation for tidal flood control. Delegations from Rhode Island and other New England states, participating in Congressional hearings held as an aftermath of Hurricane Carol, urged that hurricane damage surveys of stricken areas in New England be made with a view to recommending protection. The Governor of Rhode Island, in testimony before a Senate Public Works subcommittee, declared that most of the damages in Providence resulting from Hurricane Carol could have been prevented by dams or seawalls

in Upper Narragansett Bay. He also asserted that protective works were a Federal responsibility.

Local interests urged Federal participation, claiming that since, in principle, salt-water flooding is in no way different than fresh-water flooding, Federal responsibilities in river flood control should be extended to include tidal flood control. Further, local interests expressed the opinion that protective barriers in Lower Narragansett Bay would justify Federal participation since the interests of two states would be involved, and an important area in the bay necessary to the national defense would be affected. The cost of such large-scale engineering structures, it was considered, would be more than the states and municipalities concerned could reasonably be expected to spend.

49. PROPOSALS FOR PROTECTION

A number of specific proposals have been advanced by local interests for hurricane flood protection. The majority of these proposals have been for consideration of barriers or dams at specific locations in the bay that would afford measurable protection against tidal rises for the areas behind the barriers.

At least 15 plans involving 25 locations for barriers, as listed below, were presented in sufficient detail to merit careful examination and review.

a. Upper Providence River barrier plans

(1) Ship Street, Providence
(2) South Street, Providence
(3) Point Street, Providence
(4) Fox Point at Tockwotten Street, Providence. Two alternative plans proposed.

b. Lower Providence River plans

(1) Harbor Junction Wharf, Providence
(2) Sassafras Point, Providence
(3) Fields Point, Providence, to East Providence. Three alternative plans proposed
(4) Pawtuxet Point, Edgewood, to Sabin Point, East Providence
(5) Gaspee Point, Warwick, to Bullock Point, East Providence
(6) Conimicut Point, Warwick, to Nayatt Point, Barrington

c. Greenwich Bay plans

(1) Cowesett to Cedar Tree Point in Warwick
(2) Sally Rock Point to Buttonwoods in Warwick

d. Lower Narragansett Bay barriers. A plan for barriers across the East and West Passages near the mouth of Narragansett Bay.

e. Series of subsurface barriers. A plan for subsurface barriers in the Middle and Lower Bays.

f. Sakonnet River barriers

(1) The Hummocks, Portsmouth, to Tiverton
(2) Island Park, Portsmouth, to Tiverton
(3) McCurry Point, Portsmouth, to Tiverton
(4) Sandy Point, Portsmouth, to Tiverton
(5) Black Point, Portsmouth, to Little Compton

g. Local protective measures. In addition to the above barrier plans, local interests in the town of Bristol have requested consideration of a breakwater in the harbor to protect waterfront property and commercial and pleasure vessels against hurricane waves. A number of towns have also proposed the protection or acquisition of vulnerable beach areas and zoning of areas below an elevation of 20 feet above mean sea level, to be accomplished jointly by the State of Rhode Island and Town governments.

50. PUBLIC HEARINGS

Public hearings were held in Providence and Newport, Rhode Island, and Fall River, Massachusetts, on 1, 2 and 3 October 1956, respectively, to permit local interests to present their views concerning the character and extent of the protection desired and the need for such improvements. A total of 163 attended the meeting in Providence, 151 in Newport and 65 in Fall River. Federal, state and local officials; representatives of civic, commercial and industrial interests; and private individuals attended the hearings. A majority of the participants approved of hurricane flood-control structures in the Providence area and at the mouth of Narragansett Bay. A summary of the views and opinions expressed at the hearings appears in paragraph 65 and in Appendix G.

HURRICANE FLOOD PROBLEMS AND SOLUTIONS

51. HURRICANE FLOOD DAMAGES

Hurricane damages result chiefly from (1) salt-water flooding by the hurricane surge (2) action of storm-driven waves, (3) fresh-water flooding resulting from torrential rains, and (4) effect of high-velocity winds. This report is limited to the damages arising from salt-water tidal flooding and wave action. Fresh-water run-off and flood damages are considered only to the extent that they affect areas subject to tidal flooding. Along low coastal areas and in narrow river valleys, flooding is generally the chief concern. Hurricane Carol (1954) caused severe flooding of shorefront areas in the Narragansett Bay area, and in the following year Hurricane Diane inflicted enormously heavy flood damages along river valleys in Connecticut, Massachusetts and Rhode Island.

Hurricane damages result from loss of life and property, hazards to health, disruption of normal economic activities, and costs of evacuation and reoccupation. Some types of damage cannot feasibly be prevented although they may be relieved by careful planning. Effective protection against hurricane winds, for instance, can be relieved to some extent by the adoption of higher building-code standards, as has been done in some localities. Damages resulting from tidal flooding of coastal areas or fresh-water flooding of river valleys, however, can be significantly reduced in many cases by adequate protective structures.

52. POSSIBLE PROTECTIVE MEASURES CONSIDERED FOR NARRAGANSETT BAY

Protective measures fall into the following categories, discussed below: (a) hurricane warning and emergency flood mobilization measures; (b) revision of zoning regulations and building codes; (c) local protection, i.e., protective structures such as dikes, walls, breakwaters, bulkheads and local tidal barriers designed to protect individual portions of the shorefront subject to tidal flooding; and (d) large-scale tidal flood barriers designed to prevent a hurricane surge from entering a major portion of the bay.

a. <u>Hurricane warning and emergency flood mobilization measures</u>. A hurricane warning system, combined with emergency mobilization, would materially aid in preventing loss of life and property. However, such a system would not alleviate the problem of physical inundation of land areas. Considerable time is required for emergency precautions for homes, buildings, goods and other property such as boarding-up

and sand-bagging lower floors and windows, evacuating low-lying areas, removing goods and equipment to higher levels, pulling small craft ashore, driving vehicles to high ground, and flying aircraft out of the area. A warning system, no matter how extensive and elaborate, may not provide sufficient time for adequate precautions. The hurricane of 1938, for example, which was at one time reported stalled off Cape Hatteras, North Carolina, swept over the Narragansett Bay area, almost unannounced, only 8 hours later.

Hurricane alerts and near misses that result in "scares" only seriously interfere with the normal activities of the affected residents and mean undue hardship and great economic loss. The entire central business area of Providence, for instance, was evacuated, after long hours of sandbagging and construction of barricades, in anticipation of Hurricane Hazel (September 1954) which eventually moved up Chesapeake Bay and across Lake Erie into Canada, avoiding the Narragansett Bay area entirely. For the Narragansett Bay area, a "scare" has been estimated to cost about $325,000. Adequate hurricane warnings are necessary, however, to supplement any plan of protection for Narragansett Bay, particularly for barriers with gated openings where closures of the gates against tidal flood rises would be contingent upon evaluation of storm conditions. As part of its responsibility for improved weather services in connection with major storms and hurricanes, the Weather Bureau has established a "severe weather" network along the Atlantic coast, utilizing powerful radarscopes. The Weather Bureau office in Rhode Island, at the Theodore Francis Green Airport in Warwick, is linked to this network by means of a radar installation on Nantucket, which has a range of about 250 miles. This installation is backed by others at Boston, Worcester, Hartford and New York City.

b. Revision of zoning regulations and building codes. Consideration of the warnings and emergency measures above leads to thought of more permanent relocation of goods and equipment to higher floor levels, relocation out of the flood area entirely, or of more substantial construction to resist the destructive forces of high water and waves. State and local governments have proposed adoption of zoning restrictions to prevent new construction in critical flood areas and revision of building codes to require sturdy structures for areas where buildings were demolished by the storm tide. For existing concentrations of homes, commercial establishments and industries, such measures have met with strong opposition because of the high investment in property and the prospective loss to property owners and municipalities.

The responsibility for enacting legislation on zoning and building regulations lies with the states and municipalities concerned. After Hurricane Carol (1954) the State of Rhode Island embarked on a shore development program to aid communities by acquiring, for recreational and wildlife development, private

shorefront property endangered by recurring hurricane floods. Subsequently, the program was modified to stress beach erosion control rather than shore development. A number of communities have applied for state aid under this program.

c. Local protection. Four general classes of local works have been considered.

(1) Individual measures. Since Hurricane Carol, a number of the larger industries and business establishments in the flood area have installed permanent or semi-permanent measures to protect their physical plants against hurricane flooding. These measures include:

(a) Construction of flood-proof structures.
(b) Construction of flood walls around individual properties.
(c) Permanent closure of windows and other openings exposed to flood waters.
(d) Installation of valves or gates to prevent backup in pipe lines.
(e) Installation of pumps to control seepage and interior drainage.
(f) Changes in the utilization of space subject to flooding.

Most of these protective measures constructed by private interests are as yet untested and of uncertain effectiveness. They are also costly, not only in materials and labor, but also by reducing productivity. It is inconceivable how such measures can be generally adopted over the bay area without proving vastly uneconomical as compared to alternative flood protection methods.

(2) Protection against flooding by local barriers, dikes and walls. To be effective against hurricane tidal flooding, such structures would require heights of approximately 20 feet or more above mean sea level to protect against wave attack and wave overtopping. At many locations high walls or dikes would block access to the shorefront and would be objectionable to property owners. Losses at only a few locations, such as Providence, along the 250 miles of shoreline of the bay would warrant the high costs of such works, which are likely to cost in excess of $500 per linear foot, exclusive of pumping stations, provision for storm water drainage and gated openings for highways and railroads. At Providence, the high valuation of the area, the long history of disastrous flooding and the relatively narrow width of the Providence River indicate construction of a barrier across the river as a local protection measure. A barrier at Fox Point, Providence, is described in paragraph 57.

Business district of Providence during Hurricane "Carol" (August 1954). Millions of dollars in merchandise was lost. Foundation damage to the Howard Building in the center was a major reason for condemning this building, which is being replaced by a modern, flood-proof structure.

Photo by Tony Petre

(3) Protection against wave action by breakwaters. In areas susceptible to heavy wave attack, both during normal and hurricane conditions, breakwaters may be required to protect small craft and shorefront property against wave action. Studies of breakwaters have been requested for the protection of Bristol Harbor, an area highly vulnerable to wave attack.

(4) Protection against erosion by low walls and bulkheads. Flood waters and wave action cause widespread erosion of exposed shores. Many owners of shorefront properties have constructed concrete walls or bulkheads to protect against erosion by waves and storms. These structures, costing as much as $100 per linear foot, are subject to overtopping during major hurricanes, necessitating costly repair or rebuilding. Although low walls and bulkheads are highly practical for individual shorefront properties, in no sense can they provide adequate protection against tidal flooding.

d. Large-scale tidal flood barriers. A barrier, or series of barriers, stretching across such an indentation as Narragansett Bay, would protect the entire area above itself. Such a structure, if gated, could be designed to entirely prevent the entry of the tidal surge into the protected area; or, if provided with properly designed openings and placed below a sufficiently large area of water, would so restrict the entrance of the tidal surge as to reduce flood tides far below damage levels. The practicability of large-scale barriers of this kind depends upon extremely complex requirements of length, depth, tidal and current conditions, and the needs of navigation. The narrow passages and openings in Narragansett Bay provide a variety of natural sites for such barriers.

53. THE HURRICANE FLOOD PROBLEM

The engineering problem of hurricane flood protection in Narragansett Bay is one of selecting a feasible structure or combination of structures which will provide economically justifiable protection for as large a part of the bay's 250 mile shoreline as practicable, with a minimum disruption of existing or potential navigational, industrial and commercial, residential and other interests in the area. Review of the possible alternative methods of hurricane tidal flood control in the area indicates that while, at first glance, individual structures at the most seriously affected localities might appear most economically justified, the cost of these structures tends to be prohibitive, or their effectiveness doubtful. Since, at best, local structures such as dikes, walls, breakwaters, bulkheads, or small barriers can protect only a few miles of shoreline, the tidal flood damages which they prevent are greatly exceeded by their costs, except in limited areas of very high concentration and valuation of property, as in Providence. Conversely, although the costs of large-scale barriers are very high, the reduction in damages accruing to them tends to make them economically justifiable because of the great length of shoreline which a single barrier, or series of inter-related barriers, will protect.

Since nearly two-thirds of the very heavy hurricane tidal flood damages incurred in Narragansett Bay are distributed over a variety of localities; exclusive of Providence, along the nearly 250 miles of shoreline, it is clear that large-scale barriers will tend to be more economically justified than local protective structures. In view of this, the engineering problem of protection resolves itself into one of determining that barrier site and design or combination of barrier sites and designs which is most practicable from an engineering point of view, and which will offer economically justifiable protection for the maximum area.

54. STUDIES OF ALTERNATIVE BARRIER PLANS

Preliminary studies were made of the 15 plans proposed by local interests, and listed in paragraph 49. All of these plans are essentially for tidal flood barriers at various sites within the bay. After studies of these proposals, the following general considerations governing the selection of sites and designs of tidal flood barriers in Narragansett Bay were developed.

a. Considerations governing selection of barrier sites. It is self-evident, of course, that the selection of barrier sites will be governed by considerations of necessary length, water depth,

and foundation conditions. Certain sites otherwise desirable will prove impracticable because of unsatisfactory foundation conditions; at other sites, excessive lengths or depths may render benefit-cost ratios substantially less favorable, or prohibitive. Several other factors, however, constitute major considerations in barrier site selection. Among these the most significant are (1) the navigational requirements of vessel traffic within the bay and within the Providence River; (2) the necessity of adequate provision for tidal circulation and the discharge of fresh-water drainage; (3) problems created by build-up of the tidal flood level in the area below a barrier; and (4) fetch above the barrier in which water levels and waves may increase to damaging elevations.

(1) Navigational requirements. Except for very important special requirements for Naval craft, which must be provided witn adequate navigational openings in any proposed barrier in the Lower Bay, navigational requirements present no problem at either extreme of the bay. A barrier placed at the head of navigation, of course, presents no requirement for navigational openings. In the Lower Bay, ungated navigational openings of wholly adequate width for all present or prospective commercial vessel traffic can be provided while still admitting such a small percentage of the tidal surge as would create only a slight rise over the 120-square-mile area of the bay. A barrier placed below the confluence of the Blackstone and Providence Rivers, however, would have to be provided with watertight navigation gates which could be closed in time of a hurricane warning.

(2) Tidal circulation and fresh-water discharge. A barrier must be so designed as to provide, either by openings or sluice gates, for adequate tidal circulation to prevent pollution and the passage of interior fresh-water drainage. Barriers placed in the mid-bay or lower bay present no problem in this respect, since tidal circulation would not be adversely affected and the water area above the barrier would be sufficiently large to absorb all fresh-water drainage with only a few inches rise. A completely closed barrier at the head of navigation would present no serious problem, inasmuch as sluice gates would be adequate to provide tidal circulation and fresh-water drainage from the Woonasquatucket and Moshassuck Rivers under normal conditions, and pumping stations could be provided to take over when the sluice gates would be closed during a hurricane alert. Barriers located below the confluence of the Providence and Blackstone Rivers, however, would have to be provided with pumping stations adequate to meet a peak flood flow of 30,000 cubic feet per second from the Blackstone River drainage area, and would therefore require unusual pumping equipment and electrical power.

(3) Build-up. Hydraulic model tests have demonstrated that a barrier constructed across Narragansett Bay to block a storm surge would create some build-up, or increase in the water level below the barrier. This build-up depends mainly on the relative areas above and below the barrier. Measurements showed that build-up increases from a negligible amount at the head of the Providence River to a maximum of 2 to 3 feet in the Middle Bay and falls off to about 0.5 foot near Newport.

(4) Local wind and wave effects. A barrier that will effectively block ocean waves and hurricane tidal surges may not provide complete protection for all damage areas within the bay. As the fetch above the barrier increases, the reduced waves grow in magnitude, and the wind drives the shallow bay and river waters to higher levels. Waves generated in the 25-mile length of Narragansett Bay may reach a height of 8 feet from crest to trough. The wind effect in the length of the bay, depressing levels near the mouth and increasing levels at the head of the bay, is 3 to 4 feet, depending on wind direction and duration. This tipping of the water surface is greatest in the Upper Bay where waters are shallow. Appendix B contains a more detailed discussion.

b. Alternative plans of protection. All proposed barrier sites were reviewed in the light of these considerations. Four alternative plans for tidal flood barriers were selected as offering the best possibilities for protecting the Narragansett Bay area. A brief description of each follows:

(1) Lower Bay barrier plan. A plan for rock-fill barriers, with navigational openings, across each of the three entrances to Narragansett Bay - an East barrier across the East Passage, a West barrier across the West Passage, and a barrier across the head of the Sakonnet River at Tiverton. This plan would provide general protection for the Narragansett Bay area, preventing more than 90 percent of the $120,000,000 damages which the September 1938 hurricane tidal flood would cost today. Dimensions of the navigational openings through each of the barriers were designed to achieve a balance between effective protection and the requirements of navigation, and to permit normal tidal flow in and out of the bay without setting up violent currents around the openings. Construction would range between $69,000,000 and $109,000,000, depending on the necessity for additional features for pollution control, fish and wildlife and provision for settlement.

(2) Middle Bay barrier plan. A plan for three rock-fill barriers, with navigational openings, across the West Passage south of Greenwich Bay, across the East Passage south of Mount Hope Bay, and across the head of the Sakonnet River at Tiverton. This plan would protect all of Upper Narragansett Bay, including Mount Hope Bay, and would prevent about 75 percent of the damages which the September 1938 hurricane would cause today. The water surface behind the barriers would be large enough to dispense with the need for pumping of fresh-water drainage. Since the build-up is a maximum in the Middle Bay, the barriers would produce more severe flood conditions in the areas below than would occur with no barriers. These barriers would cost approximately $70,000,000.

(3) Fields Point barrier plan. A plan for a rock- and earth-fill dam at Fields Point, Providence, across the Providence River, with a pumping station and gate for navigation. This dam would provide protection for all of Providence and a major part of East Providence at a cost of about $48,000,000, and would prevent about 50 percent of the damages the September 1938 flood would cause today. Pumping of river drainage would be necessary. Build-up of about 0.8 foot below the barrier would increase flooding along both banks of the lower Providence River and in the Middle Bay.

(4) Fox Point barrier plan. A plan for a concrete dam at Fox Point, Providence, across the Providence River, with a pumping station and sluice gates for tidal interchange. This plan would provide complete protection for the center of Providence at a cost of about $16,500,000. Although only a very small area would be protected, it is an area which accounts for about 35 percent of the total flood damages in the Narragansett Bay area. Navigation gates would not be required since the site is close to the head of navigation. Since the build-up below this barrier would be negligible, no significant increase in flooding would occur below it.

55. SELECTION OF A PLAN OF PROTECTION

As indicated in paragraph 53, preliminary study indicated that tidal flood barriers offered more effective and economically justifiable protection for Narragansett Bay than individual local protective structures. Analysis of the four barrier sites selected for complete study on the basis of preliminary investigations serves to eliminate all potential sites between the confluence of the Blackstone and Providence Rivers and the Lower Bay. As indicated in paragraph 54 and again in paragraphs 54b (2) and (3), build-up, which increased from a negligible amount at the head of the Providence River to a maximum of between 2 and 3 feet in the Middle Bay, after which it decreases to about 0.5 foot at Newport, would cause a seriously damaging increase in the tidal flood levels below the barrier sites, either for the Fields Point location or for the considered Middle Bay location. Similar problems would clearly obtain for any proposed intermediate points. In addition, as noted in paragraph 54 the Fields Point site, or any other below the confluence of the Providence and Blackstone Rivers, would radically increase construction costs by reason of the very heavy pumping facilities necessary to discharge the flood flows of the Blackstone River.

In addition to these considerations, however, a barrier located in the Providence area, and designed to provide local protection to the city, will eliminate about 35 percent of damages incurred in the entire Narragansett Bay area, leaving virtually the whole bay, including extensive Naval installations, with no protection. Conversely, Lower Bay barriers, although they will overwhelmingly reduce damages throughout the majority of the shoreline, will not provide satisfactory protection for Providence and the Upper Bay area inasmuch as the 25-mile fetch up the Bay will allow hurricane winds to generate damaging storm waves with high levels at the head of the bay. In view of this, it is considered that both barriers are necessary to provide a satisfactory plan for the over-all protection of Narragansett Bay against hurricane tidal flooding. Consideration was therefore given to specific locations for the Fox Point and Lower Bay barriers.

a. Fox Point barrier. In the 0.8 mile of the Providence River between the head of navigation and the confluence of the Providence and Blackstone Rivers, there would be no significant difference in pumping requirements, construction costs, or build-up below the barrier. The Fox Point site, therefore, was selected as being farthest downstream, and hence, protecting the greatest area of the center of Providence. A barrier at

Fox Point would give the highest ratio of hurricane protection for expended money of any single site in the bay. It would completely protect downtown Providence, including the South Street and Manchester Street steam-electric plants of the Narragansett Electric Company.

b. Lower Bay barriers. The most practicable sites in the Lower Bay are in the three narrow entrances to the Bay. For a closure of the East Passage at the mouth of the Bay there is little choice among alternative sites, since the narrowest reach, off Bull Point opposite Newport, is only about one mile long. In this reach, deep waters, up to 165 feet deep, cannot be avoided. The site selected for the East barrier after careful study is about 2,500 feet southwest of the 54-degree turn in the navigation channel of Bull Point. This, more than any other alternative site, would facilitate passage of Naval and commercial vessels.

After study of five alternative barrier sites in the West Passage in a 3-mile reach extending from the Jamestown Bridge south to Bonnet Shores, a site about 600 feet south of the Jamestown Bridge was selected. Although barriers farther south in the West Passage would protect a larger area, the Jamestown Bridge site was chosen to take advantage of better foundation conditions, with consequent need for smaller quantities of rock in construction, and to combine the opening in the barrier with the 600-foot navigational opening in the existing bridge span.

In similar fashion, various sites were considered to close off the head of the Sakonnet River. A site at the existing stone bridge at Tiverton, connecting Tiverton and the Island Park area in Portsmouth, was selected as providing protection to the greatest part of developed property in the immediate area, at the minimum construction cost.

HURRICANE FLOOD CONTROL PLAN

56. GENERAL

The plan selected for the protection of Narragansett Bay against hurricane tidal flooding consists of (1) a barrier located at Fox Point on the Providence River, designed to provide protection for the greatest practicable area of the center of Providence; and (2) a series of Lower Bay barriers, comprising the east, west, and Tiverton Barriers, all provided with navigation openings, designed for the general protection of Narragansett Bay.

57. FOX POINT BARRIER

a. General description. This structure, about 1,100 feet long, would be a concrete gravity dam across the Providence River in Providence, from Henderson Street on the west bank to Fox Point on the east bank (see Plates 3 and 4). It would include four sluice gates for normal river flow, and a pumping station for passing river flow under flood conditions. Reinforced concrete land walls at either end would tie into high ground on Blackstone Street on the west end and Benefit Street on the east end. The four sluice gates, each 20 feet wide by 24 feet high, would be of a drop type, closing by gravity when released, to prevent entry of flood waters from the bay. They would be capable of discharging all river flow, including full flood runoff, at times of no hurricane surge. The concrete pumphouse would contain five large pumps capable of discharging storm water drainage and river flow through the barrier when the sluice gates would be closed to a tidal surge. An inlet structure with control gate and sheet piling canal, at the west end of the barrier, would provide about 1,300 cubic feet per second of cooling water for generating stations of the Narragansett Electric Company.

b. Geology. The Providence River at Fox Point is shallow and underlain by organic silt up to 15 feet in depth, except in dredged areas. Below the silt are layers of sand and silt, with some gravel, having a total thickness of 50 to 70 feet. Below this is glacial till, sloping gently to the west, at a depth varying from about 82 feet below mean sea level at Fox Point to about 115 feet below mean sea level near the west bank. Firm bearing would be furnished by a penetration of foundation piles into this glacial till. For more detailed geological information see Plate 4 and Appendix E.

c. Design

(1) Layout. Various alignments of the Fox Point barrier were considered. The proposed plan would fit the existing conditions best, would cause the least disruption to the operations of the Narragansett Electric Company, and would tie in best with any proposed future wharfage or highway use. A layout with the pumping station on the west end of the barrier was considered, but the proposed layout would provide much better access to the site, both for construction and for maintenance, and would be more economical to construct (see Appendix F).

(2) Construction materials. Several different types of construction were considered, and a detailed design and cost comparison was made between the proposed concrete gravity section and an earth-and-rock-fill section. The concrete section was slightly superior from the viewpoint of economy, engineering simplicity, and adaptability for future use.

(3) Grades. The 1938 hurricane flood level at Providence has been measured at 15.7 feet above mean sea level. The design flood would be three feet higher. The design of the barrier, with deck for wharfage or highway use at 12.5 feet above mean sea level, and backwall at elevation 22.5 allows for 3.8 feet of freeboard.

(4) Pumping capacity. The pumping station would contain five large pumps having a combined capacity of 8,000 cubic feet per second at a differential head of 22 feet. With a design hurricane surge and a flood runoff of this amount, the pumps could therefore draw the pool down to an elevation of about three feet below mean sea level. In case of the improbable combination of a full flood runoff of 9,200 cubic feet per second in the river and a design tidal surge in the bay, the pumps could discharge the full runoff by reducing the differential head. This would be accomplished by allowing the fresh water pool to rise to an elevation of three feet above mean sea level, a stage well below damage level and little above the mean high water line. At the time of a hurricane surge, both the sluice gates and the cooling water intake through the barrier would be closed. The cooling water would be taken from and later discharged into the fresh water pool, without increasing the pumping requirements.

58. LOWER BAY BARRIERS

a. General. The Lower Bay barriers described below are based on preliminary studies. Completion of detailed design studies that would prove satisfactory to all interests must await the results of further studies of the effects of the barriers on present conditions within the bay, principally on navigation, pollution and fisheries. The final plan may differ from the plan herein described in providing for larger navigational openings AND in the West barrier, ~~and~~ the addition of navigation and sluice gates.

b. East barrier

(1) Description. This would be a massive stone structure extending from Conanicut Island 3,200 feet to Newport Neck (see Plate 5). It would have a quarry-run stone core, capped and faced with heavy derrick stones to a depth of 20 feet below mean sea level. The top would be 20 feet in width, at an elevation of 22 feet above mean sea level. With sides sloping one vertical on two horizontal the maximum base width of the structure would be more than 700 feet. The barrier would be oriented at right angles to the existing navigation channel, and a navigation opening 1,000 feet wide and 50 feet deep at mean low water would be centered upon this channel.

(2) Geology. The East Passage of Narragansett Bay at the barrier site occupies a deep trough with water depths reaching 160 feet below m.s.l. Seismic indications are that bedrock lies at a depth of 400 or more feet below m.s.l. The character of the materials overlying bedrock could not be determined by the seismic method because velocity determinations about equalled that of water. The assumption that fine-grained materials comparable to those found elsewhere in the bay exist at the site has led to the adoption of large settlement factors.

(3) Design. In view of the huge quantities of fill necessary, the problems of placing it in deep water, and the probability of violent wave attack, rock fill would appear to be mandatory for the East barrier. Quarry-run rock would be adequate for the core, but the need for protection against wave action would require that the top and upper sides be protected with derrick stones of 20 ton minimum size. Complete protection against the 25-foot waves that could occur at the East barrier might require even larger stones.

Site of Fox Point Barrier across Providence River from Henderson Street on the left (West) to Fox Point on the right (East).

Photo by Rhode Island Development Council

Site of East Barrier. This Barrier would be a rock-fill dam extending from Jamestown to Newport with a 1,000-foot navigation opening.

Photo by Providence Journal Co.

c. West barrier.

(1) Description. This structure, 7,100 feet long, of the same general type as the East barrier, would cross the West Passage about 600 feet south of the Jamestown Bridge (see Plate 6). A navigation opening 400 feet wide and 40 feet deep at mean low water would be centered on the existing ship channel, which passes between the two main piers of the bridge. Alternative sites as far south as Bonnet Shores were considered, as discussed in Appendix F.

(2) Geology. The West Passage site crosses a preglacial depression whose depth is not known but may approach 400 feet west of the ship channel. Materials in the depression are fine-grained below an elevation of 40 feet below m.s.l. and somewhat coarser above, presenting moderately favorable foundation conditions for the barrier. A rock foundation for gates exists beneath the center of the ship channel at an elevation of 80 feet below m.s.l. (see Appendix E).

(3) Design. The West barrier design would be substantially the same as for the East barrier with regard to grades, slopes, and cross-section, although the wave action may be a little less severe at this site.

d. Land wall.

The highway across Round Swamp on Conanicut Island would be raised to 22 feet above mean sea level and protected by stone facings on the slopes to prevent flooding across the island.

e. Tiverton barrier.

(1) Description. This structure would consist of an earth-and-rock fill dike along the shorelines of the Island Park and Tiverton areas at the head of the Sakonnet River, and a crossing at the Old Stone Bridge between Island Park and Tiverton (see Plate 7). The total length would be 9,425 feet, of which about 1,200 feet would lie between the existing bridge abutments in the river. A navigation opening 100 feet wide and 30 feet deep, referred to mean low water, would be provided which would be closed during hurricanes by a pair of sector gates. The existing town beaches would be maintained on the seaward side of the dikes, with access ramps provided.

(2) Geology. All materials with the exception of 5 to 10 feet of surficial organic silts in the vicinity of the ship channel are granular, ranging from fine sand to gravel. Bedrock lies at about 400 feet below m.s.l., but outcrops near the east abutment of the barrier (see Appendix E).

(3) Design. The major part of the Tiverton barrier is above mean sea level, and therefore an earth-and-rock-fill structure with the slopes protected with placed rock would give the necessary stability at greater economy than rock fill. The position of the barrier, about 11 miles above the mouth of the Sakonnet River, would result in a much less severe wave condition than at the East and West barriers, and a top elevation of 20 feet above mean sea level has been selected.

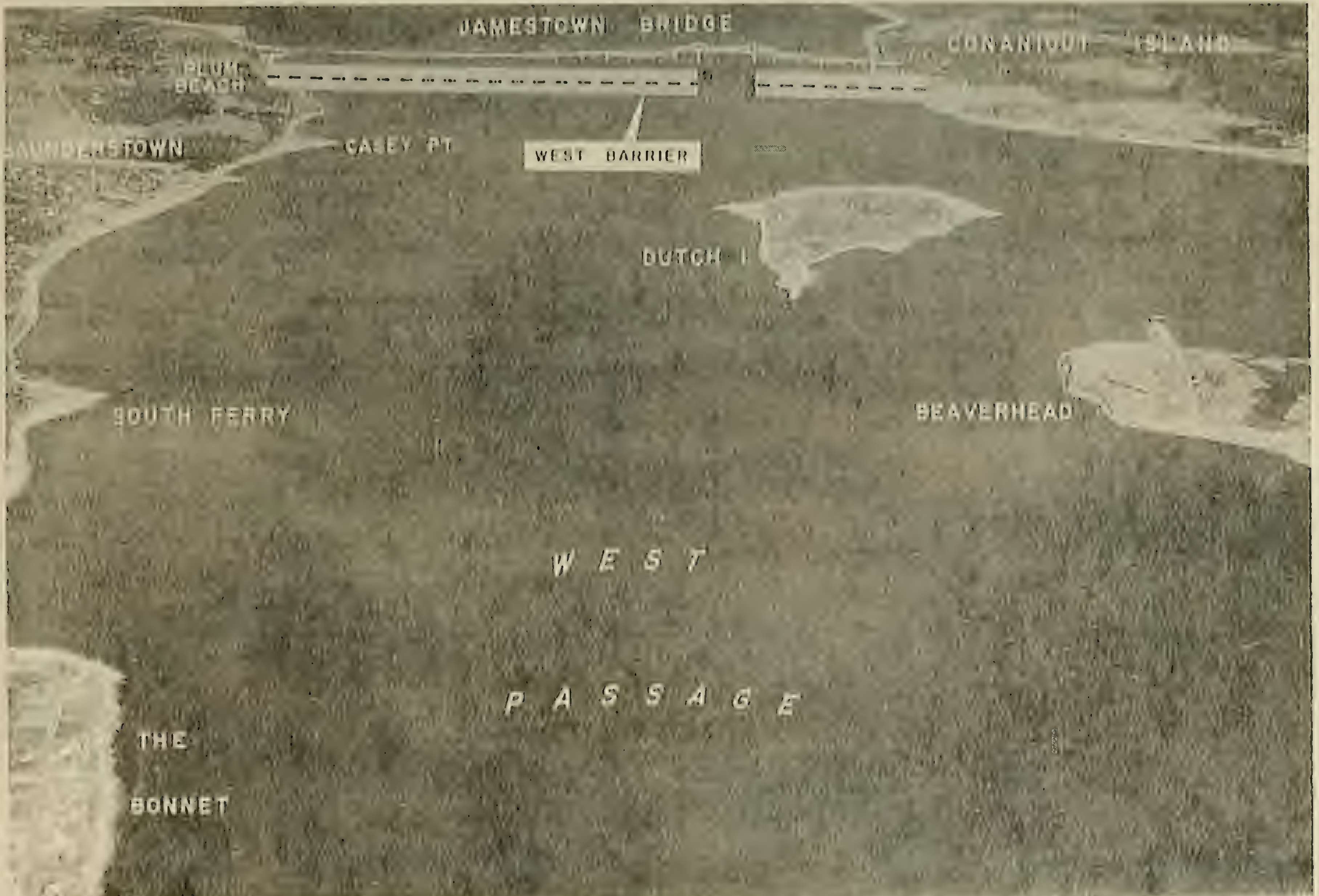
f. Hydraulic and hydrologic considerations. The design of the Lower Bay barriers was based on criteria and preliminary studies as follows:

(1) The design tidal flood of 12.8 feet above mean sea level at the mouth of the bay. This was based on initial studies of maximum winds by the U. S. Weather Bureau, and of tidal surges by the Beach Erosion Board and Texas A & M Research Foundation.

(2) Build-up in the flood tide levels below the East and West barriers at the mouth of the bay of approximately 0.5 foot as determined from hydraulic model tests. The build-up south of the Tiverton barrier is more than 2 feet.

(3) The design wave height of 25 and 20 feet at the East and West barriers from crest to trough, derived by the Beach Erosion Board and substantially confirmed by observations of the Narragansett Marine Laboratory.

(4) Wave run-up on the structures above the design tidal flood would result in overtopping of the East and West barriers by 6 feet or more. Preliminary studies indicated it was impracticable to design the structures sufficiently high to avoid overtopping; the volume of water carried into the bay could be absorbed by the 120 square-mile drainage area of the bay with a rise of less than 0.3 foot. Further study of slopes of structures and stone sizes is required to assure design of a stable structure.



Site of West Barrier. This Barrier would be a rock-fill dam across the West Passage 600 feet south of the Jamestown Bridge with a 600-foot navigation opening.

Photo by Providence Journal Co.

Site of Tiverton Barrier. This Barrier would be an earth and rock-fill dike along shore-lines of Island Park and Tiverton areas with a 100-foot navigation gate at Old Stone Bridge.

Photo by Providence Journal Co.

(5) Unusually high tides are likely to occur in advance of a hurricane surge, as they did in September 1938, causing some inflow and a small rise of the bay in advance of the hurricane surge.

(6) Inflow of hurricane waters through the navigation openings was based on model tests. Further testing would be desirable to determine the most effective shape of the openings and distance across the sill normal to the opening.

(7) Design streamflow of 84,000 cubic feet per second (fresh-water runoff) would result in an increase of approximately 0.3 foot in the level of the bay.

(8) The rise in water level from Newport to Providence (wind setup) as a result of design wind blowing across the 25-mile fetch is estimated at 3.1 feet but would vary widely with wind direction and intensity.

(9) Emptying of the bay to normal levels would occur rapidly after a hurricane has passed. The northwest winds which follow after passage of the storm center would very likely speed this up. Since the waters of the bay would be tipped upwards to the north it is likely that the water will rock back towards the barriers at the mouth. The rise in water level likely to occur in the Lower Bay would be small because of the damping action of the islands and the deep water in the lower end of the bay above the barriers.

g. Navigation openings. These are a key to effective design of the Lower Bay barriers. The navigation openings were selected with a view to:

(1) Fixing the openings small enough to effectively restrict the entrance of hurricane surges and provide a reasonable degree of protection in the bay as a whole.

(2) Provide openings of large enough width and depth for the passage of commercial and Naval vessels, without creating excessively fast currents under normal conditions.

(3) Provide openings large enough to prevent adverse effects on water quality, marine life and normal uses of the bay. In the preliminary design navigation openings were selected as follows:

East barrier: 50-foot depth and 1000-foot width at mean low water.

West barrier: 40-foot depth and 400-foot width at mean low water with 1 on 1.5 side slopes.

Tiverton barrier: 30-foot depth and 100-foot width at mean low water; closed during a hurricane by a pair of sector gates.

With the selected navigation openings, model tests, adjusted for wind effects, show that the design flood would rise to elevations of 4.8 feet above mean sea level at Newport and 8.9 feet above mean sea level at Providence. Substantially complete protection would be obtained for a flood equal to or less than the tidal flood of September 1938. Model tests were made for various other sizes of openings. Thus it was determined that the largest opening which would give effective protection is about 60,000 square feet (see paragraph 62). Although such openings meet the needs of commercial vessels, larger openings are desired for Naval vessels, as discussed in paragraph 74. If the navigation opening in the East barrier is increased to 1,500 feet by 60 feet, the design flood as reduced by the barriers would rise to an elevation of 7.3 feet above mean sea level at Newport and 11.3 feet above mean sea level at Providence; substantial damages would result from both the design flood and a flood of the 1938 magnitude.

The only possible means of providing the large openings required for naval use, and yet obtaining effective protection, are through the use of gates. Gates to close openings 400 feet or more in width and over 60 feet in depth are without precedent. Detailed design studies and model tests would be required before recommending such construction. Operation and maintenance of gates exposed to a tidal surge of 13 feet and ocean waves of 25 feet would be very costly.

59. LANDS, RIGHTS-OF-WAY AND RELOCATIONS

Access to the site of the Fox Point barrier presents no serious problem. Rights-of-way would be necessary, but materials could be obtained from existing sources, and relocations would be relatively slight.

The Lower Bay barriers would require one or more new quarries and rights-of-way to the water for barging or to the site for end dumping. At the west end of the West barrier, a number of small beach houses would require relocation. The east end of the East barrier would tie into higher ground at one of the large estates in Newport. At the Conanicut Island ends of both barriers, and for the land wall on the island, lands and rights-of-way would be required.

The Tiverton barrier would require shorefront easements, rights-of-way and a few relocations. It is easily accessible from both ends.

60. OPERATION AND MAINTENANCE

a. Fox Point barrier. The Fox Point barrier would ordinarily require no operation and the sluice gates would be left open for river flow and tidal flushing. During the hurricane season, however, maintenance personnel would stand by. The sluice gates and cooling water intake gate could be closed very quickly, hence, their closure would not be necessary until a relatively late stage of the hurricane warning, but preferably at a low tide. Upon the close approach of a hurricane, the gates would be closed, and the fresh water pool kept low by pumping.

Maintenance of the pumps and motors within the pumping station would necessitate periodic testing, involving running all motors and pumps for a short time and checking performance.

b. Lower Bay barriers. The East and West barriers as presently considered would require no operation. Maintenance would be limited to replacing stone dislodged by wave action, and maintaining the quarry as a source of rock fill.

The Tiverton barrier would require operation of the sector gates. These gates would be closed before the hurricane danger became acute, and would be left closed until the danger had passed. Therefore, periodic testing of the gates and operating machinery and ordinary maintenance of embankment, concrete features, and equipment would constitute the chief operation requirements.

61. HIGHWAY CROSSINGS UTILIZING BARRIERS

a. Fox Point barrier. The design of the Fox Point barrier is adaptable to possible future use as a highway crossing, and access to and across it is a feature of the present plans.

b. Lower Bay barriers. The size of the navigation opening and the vertical clearance required would make a highway crossing of the Lower Bay barriers expensive. Such a crossing at the Tiverton barrier would not be necessary, because of a newly constructed highway bridge less than one mile upstream.

62. DEGREE OF PROTECTION

The Fox Point barrier, as the first unit of the plan to be constructed, would provide full protection for the center of Providence. The Lower Bay barriers, to be constructed later, would afford general protection to the bay and practically eliminate high-water damage from floods equal to those of 1938 and 1954, although some wave damage would remain, particularly in the upper bay area. However, the degree of protection provided by the Lower Bay barriers will depend on the dimensions of the navigation openings, which are subject to adjustment in final design studies. The degree of protection which would be provided by each unit of the plan is set forth in further detail below:

a. Protection by Fox Point barrier. At the time of a hurricane warning, sluice gates in the barrier would be closed as near to low tide as practicable and pumps operated to maintain the pool level above the barrier below mean sea level. In the event of the combination of the design stream flow from the Woonasquatucket and Moshassuck Rivers coincident with the design tidal flooding from the bay, a very unlikely occurrence, the pool level might rise as high as 3 feet above mean sea level, which is well below the zero damage elevation of 6.7 feet above mean sea level.

b. Protection by Lower Bay barriers. The effectiveness of the Lower Bay barriers in reducing hurricane tide levels has been based mainly on the data provided by the hydraulic model of Narragansett Bay constructed at the Waterways Experiment Station in Vicksburg, Mississippi. Using prototype data from hurricanes of record, the model has reproduced both normal and hurricane tides with and without barriers in place. In the model, the Narragansett Bay area has been reproduced to a horizontal scale of 1 to 1,000 and a vertical scale of 1 to 100. Movement of the tides are reproduced on a time scale of 1 to 100 so that the normal astronomical tidal cycle of 12.4 hours in the bay is reproduced in about 7.5 minutes. A tide generator is used to simulate normal ocean tides, the rise and fall of water levels

being measured at gaging stations at various points in the model. Similarly, hurricane surges are reproduced by a large wave machine and the tidal surge can thus be superimposed on the astronomical tide. Results of the model were adjusted for wind effects in the bay (see Appendix B).

The model tests have shown that with a surge equal to that which occurred during the hurricane of September 1938, Lower Bay barriers would reduce the still-water level at Providence by 8 feet, from an elevation of 15.7 feet above mean sea level to an elevation of 7.7 feet. At Newport, the level would be reduced by 7.4 feet from the observed level of 11.0 feet above mean sea level to an elevation of 3.6 feet. Plates 8 and 9 show maximum tidal levels that actually occurred in the area during the 1938 hurricane and the reduced levels that would occur with the Lower Bay barriers in place. With a design flood, the still-water levels would be reduced by 8 to 10 feet. The reduction in hurricane tide levels with the plan of protection in effect is shown in Table 4 for key locations in the bay.

TABLE 4

REDUCED FLOOD LEVELS WITH PLAN IN EFFECT
NARRAGANSETT BAY AREA

Locality	Experienced Flood Level		Reduced Flood Level		Reduction	
	Sept. 1938 Flood	Design Flood	Sept. 1938 Flood	Design Flood	Sept. 1938 Flood	Design Flood
Providence	15.7	18.7	0.0(1) 7.7(2)	3.0(1) 8.9(2)	15.7(1) 8.0(2)	15.7(1) 9.8(2)
Bristol and East Greenwich	13.6	16.1	4.7	5.9	8.9	10.2
Fall River and Somerset	13.8	16.3	5.1	6.3	8.7	10.0
Newport	11.0	13.0	3.6	4.8	7.4	8.2

Notes:
Elevations are in feet above mean sea level.
(1) Above Fox Point barrier
(2) Directly below Fox Point barrier

63. EFFECTS OF THE PLAN ON NORMAL CONDITIONS IN BAY

a. Fox Point barrier. The Fox Point barrier would be constructed close to the head of navigation in Providence and would contain no navigation openings. About 700 feet of wharf space for commercial navigation could be provided at the barrier, which would replace existing wharfage used by a small amount of commercial shipping above Fox Point and provide additional wharfage for the port of Providence. Under non-hurricane conditions, the sluice gates of the Fox Point barrier would provide for free movement of tidal flow and unrestricted circulation through the barrier. The tidal range would be unaffected in the 40-acre area above the barrier and no additional pollution problem would be created. During a hurricane alert, when the sluice gates would be closed to prevent tidal flooding of the area behind the dam, runoff from the Woonasquatucket and Moshassuck Rivers, plus storm sewage from the city of Providence, would be pumped through the dam. As fish and wildlife values and recreational values are non-existent above Fox Point, the barrier would have no effect on these. The design provides for continuing the supply of 1,300 cubic feet per second of cooling water to the plants of the Narragansett Electric Company. The cooling water drawn from below the barrier would be discharged into the pool above the barrier, thus providing a discharge through the sluice gates considerably in excess of the freshwater flows from the rivers.

b. Lower Bay barriers. Barriers designed for the Lower Bay to provide protection against hurricane tidal flooding must of necessity restrict the entrance of the tidal surge so as to lower the flood tide level below the point where significant damages are incurred. Such structures will restrict the tidal range and currents within the bay, with possible long range effects on temperature, salinity, flushing and important related matters, such as navigation, pollution and fisheries. Extensive research, model tests and studies of these complex matters would be required for a satisfactory final design. The preliminary studies of these effects are discussed below.

(1) Basic studies. The present conditions in the bay were determined from available data of the U. S. Coast and Geodetic Survey and a special hydrographic survey by the Narragansett Marine Laboratory of the University of Rhode Island. Regular observations of the latter extended over a period of 9 months and provided essential

information on temperatures, salinities, currents and circulation, and bottom conditions. Preliminary estimates of the effects of the Lower Bay barriers on these conditions were made from hydraulic model tests and studies by the Narragansett Marine Laboratory and other agencies, as described below:

(2) Tidal range and currents. Model tests have shown that the Lower Bay barriers would decrease the tidal range by approximately one-third. Mean high tide elevation would be lowered about 0.8 foot and mean low tide elevation would be raised an equal amount. Tidal currents would probably be reduced about 30 percent, except in the navigation openings as noted below. The distribution of normal tidal currents and their direction would be unaffected. The effect of the reduction in tidal range on navigation is discussed below.

(3) Navigation. While the reduction in tidal range would not materially affect the low-water depth of the dredged navigation channels it would affect the depth available in the Upper Bay for navigation and berthing of the largest commercial vessels which depend on high tide. This matter may be resolved by sluice gates in the barriers which would eliminate most of the reduction in tidal range. At the time a final decision is reached on the size of the navigation openings, it would be possible to determine whether the problem of ship clearance is serious enough to warrant modifying the barriers by introducing sluice gates.

At the openings in the barriers maximum flood and ebb currents between 4 and 5 knots could be expected. This would adversely affect navigation, particularly small boats of low engine power. For comparison, currents through the Cape Cod Canal range from 3 to 6 knots and at the entrance to Long Island Sound currents range from 3.8 to 5.6 knots. The navigation openings referred to mean low water of 1,000-foot width by 50-foot depth in the East barrier and 400-foot width by 40-foot depth in the West barrier, are considered by the Navy to be inadequate to provide the requisite margin of safety for Naval use under all circumstances. Negotiations are in progress with the Navy on dimensions that will meet their requirements and at the same time retain a high degree of protection in the design.

(4) Temperatures and salinity. Preliminary studies indicate that the effect of the barriers on water temperatures within the bay would be negligible, amounting to no more than 0.5°F. Normal salinity ranges from 18 parts per thousand at

Providence to 32 parts per thousand at Beavertail Point. Due to the reduction in tidal range that would result from the barriers, the salinity within the bay would be reduced by about 1 to 3 parts per thousand.

(5) Pollution and fisheries. Effects of the Lower Bay barriers on pollution and fisheries are undetermined. Their evaluation is a difficult problem involving intimate knowledge of the present physical, chemical and biological makeup and balance in the bay and the new balance resulting from the barriers. Analytical studies are in progress by the U. S. Public Health Service and U. S. Fish and Wildlife Service. In conjunction with these studies, additional tests are in progress using the model at the Waterways Experiment Station, both with and without the barriers, of the salinity regimen and distribution, flushing action and dilution of wastes, sedimentation patterns and rates, and temperature range and distribution in Narragansett Bay.

(6) Beach erosion. Detailed information concerning beach erosion in the area above the Lower Bay barriers of Narragansett Bay is not available. It is known, however, that beach erosion problems exist along sections of the shore in Warwick and Jamestown and possibly in other areas. The Lower Bay barriers are not expected to have any harmful effects as far as beach erosion is concerned. On the contrary, they would have definite beneficial effects by reducing wave attack behind the barriers.

64. ADDITIONAL STUDIES OF LOWER BAY BARRIERS

The combination of structures which comprise the Lower Bay barrier plan is not one that can be built immediately. The scope of the problem is such that further expensive studies and research investigations are required. These studies include the following:

a. Design flood.

(1) Determination of the maximum probable hurricane as a check on the selected design wind field.

(2) More complete investigations of tidal surges for effects of three different types of storms.

(a) the fast moving storm, which gives a high sharp crest

(b) the slower moving storm, which gives a lower crest but a greater volume, and

(c) the stalled type.

b. Negotiations with the Navy.

(1) Decisions on the minimum size of navigation openings acceptable to the Navy in the light of protection requirements and strategic considerations.

(2) Investigation of the need for traffic control and construction and maintenance procedures.

c. Model tests and analytical studies.

(1) Additional tests of barriers under flood conditions with emphasis on (a) openings desired by the Navy; (b) the most effective shape of the barriers; and (c) surges having a lower flood crest but greater volume than the design flood.

(2) Tests on sedimentation, tidal flushing and salinity.

(3) Analytical studies of termperature changes, based upon the salinity tests in the model.

d. Foundation investigations. Deep water borings and sampling at the East barrier site, for correlation with the seismic explorations and for testing. Borings at the West barrier site to supplement the boring records relating to the Jamestown Bridge, 600 feet to the north.

e. Pollution. Studies of flushing rates and the effect of barriers on pollution of the bay waters.

f. Fish and wildlife.

(1) Completion of the inventory-type studies now in progress of existing biological conditions, and shellfish and finfish.

(2) Studies of the bay as a spawning and nursery area for oceanic fish species.

(3) Studies of the tolerance of various species to changes of termperature, salinity and the like.

(4) Determination of the effects of barriers on fisheries and resultant changes, if any, in navigation openings and sluice gates.

g. Design studies. Completion of the studies described above is required as a part of the design studies for the Lower Bay barriers.

65. VIEWS OF LOCAL INTERESTS

At the public hearings, local interests presented their views on the proposed plan of protection (see paragraph 50 and Appendix G). The views and opinions of the groups and individuals who attended the hearings are summarized as follows:

a. A majority, including the Governor of Rhode Island, the Providence Hurricane Protection Committee, and the Mayors of Providence and Fall River, expressed general approval of the two-unit plan of protection, consisting of the Fox Point barrier in the Upper Bay and the East barrier West barrier and Tiverton barrier in the Lower Bay and Sakonnet River. The Governor of Rhode Island also urged continuation of studies of the effects of the barriers on the natural resources and physical conditions within the bay. In regard to financing, he stated that the policy set forth for river flood control projects should be followed, the Federal government assuming costs of all basic construction and local interests assuming costs of all necessary rights-of-way and land acquisitions, and of maintenance. He also stated that local protection would be necessary wherever barriers by themselves could not prevent damaging flooding of some areas. A group representing the Town of Bristol requested consideration of breakwaters in Bristol Harbor to protect against damaging waves.

b. Several individuals, while endorsing the two-unit plan of protection, were concerned with the effects of the Lower Bay barriers on fish and wildlife, pollution, navigation, Naval requirements and the physical characteristics of the bay. Others expressed opposition to the Lower Bay barriers on the grounds that they would have adverse effects on present conditions within the bay or that their ultimate effects on present conditions could not be evaluated for several years, and proposed local protection or other methods, such as better hurricane warning systems, Federal flood insurance and individual protection measures, as alternatives.

ESTIMATES OF FIRST COST

66. All estimates have been prepared on the basis of 1956 price levels, using unit prices based on actual bid prices for similar work in the region, with corrections to allow for the size and character of the proposed plan. The total estimated first cost of the Fox Point barrier is $16,500,000. Tables 5, 6, and 7 summarize the principal items of first cost; detailed costs are given in Appendix F. The total estimated first cost of the Lower Bay barriers ranges from a lower limit of about $69,000,000 to an upper limit of about $109,000,000, depending on Naval requirements, foundation conditions, and facilities installed for pollution control and fisheries. The lower limit might be maintained under optimum conditions, such as a high degree of foundation stability and a minimum of further changes in design. The upper limit allows for larger foundation settlement in the East barrier and includes provision for navigation gates and possible sluice gates in the West barrier.

ESTIMATES OF ANNUAL CHARGES

67. Annual charges are based on 2.5 percent interest on the investment, amortized over a 50-year period, plus the estimated costs of maintenance and operation. The estimated annual charges are $732,000 for the Fox Point barrier. Annual charges for the Lower Bay barriers range from $2,580,000 for the lower limit of first cost to $4,167,000 for the upper limit. Tables 5, 6, and 7 summarize the annual charges; a detailed summary is given in Appendix F.

TABLE 5

FIRST COSTS AND ANNUAL CHARGES

Fox Point Barrier - Providence, Rhode Island

Item	Federal	Local	Total
	FIRST COST AND INVESTMENT		
Construction of Barrier and Pumping Station	$15,345,000		$15,345,000
Lands and Damages		$200,000	200,000
Electric Power Installation	835,000		835,000
Sewer and Drainage Modifications	———	120,000	120,000
Total First Cost	$16,180,000	$320,000	$16,500,000
Interest during Construction	404,000	8,000	412,000
	$16,584,000	$328,000	$16,912,000
	ANNUAL CHARGES		
Interest on Investment	$ 414,000	$ 8,000	$ 422,000
Amortization	170,000	4,000	174,000
Estimated Tax Losses		2,000	2,000
Maintenance and Operation	———	134,000	134,000
Total annual charges	$ 584,000	$148,000	$ 732,000

TABLE 6

FIRST COSTS AND ANNUAL CHARGES

Lower Bay Barriers - Narragansett Bay

Estimate of Minimum Cost

Item	Federal	Local	Total
Construction of barriers, dikes and walls	$ 67,273,000	$ 1,617,000 (1)	$ 68,890,000
Lands and Damages	-	110,000	110,000
Total First Cost	$ 67,273,000	$ 1,727,000	$ 69,000,000
Interest during Construction	2,527,000	65,000	2,592,000
Total Investment	$ 69,800,000	$ 1,792,000	$ 71,592,000

ANNUAL CHARGES

Item	Federal	Local	Total
Interest on Investment	$ 1,742,000	$ 45,000	$ 1,787,000
Amortization	715,000	18,000	733,000
Estimated Tax Losses		3,000	3,000
Operation and Maintenance	57,000	-	57,000
	$ 2,514,000	$ 66,000	$ 2,580,000

(1) Cash contribution to first cost in lieu of annual operation and maintenance of structures.

TABLE 7

FIRST COSTS AND ANNUAL CHARGES

Lower Bay Barriers - Narragansett Bay

Estimate of Maximum Cost

Item	Federal	Local	Total
Construction of barriers, dikes and walls	$ 105,203,000	$ 3,687,000 (1)	$ 108,890,000
Lands and Damages	-	110,000	110,000
Total first cost	$ 105,203,000	$ 3,797,000	$ 109,000,000
Interest during construction	5,260,000	190,000	5,450,000
Total Investment	$ 110,463,000	$ 3,987,000	$ 114,450,000

ANNUAL CHARGES

Interest on Investment	$ 2,760,000	$ 100,000	$ 2,860,000
Amortization	1,133,000	41,000	1,174,000
Estimated Tax Losses	-	3,000	3,000
Maintenance and Operation	130,000	-	130,000
	$ 4,023,000	$ 144,000	$ 4,167,000

(1) Cash contribution to first cost in lieu of annual operation and maintenance of structures.

68. EVALUATED TANGIBLE BENEFITS

Benefits which have been evaluated for the plan include flood-damage prevention benefits and benefits from elimination of scare costs. Benefits that may be realized from breakwaters and other measures in several localities will be presented in a future report.

Average annual flood-damage prevention benefits were derived by determining the difference between annual losses under present conditions (see paragraph 45) and the losses remaining after construction of the projects in the plan. Annual flood-damage prevention benefits in the areas of the bay protected by the plan amount to $5,902,000, of which $1,697,000 would accrue to the area above the Fox Point barrier and $4,205,000 to the area between the Fox Point barrier and the Lower Bay barriers. Benefits from the elimination of scare costs would amount to $98,000 annually, of which $36,000 would accrue to the area above the Fox Point barrier and $62,000 to the area between the Fox Point barrier and the Lower Bay barriers. Total annual benefits for the two-unit plan amount to $6,000,000.

A recurrence during the fifty-year amortization period for the project of the flood stages produced by the three most severe hurricanes of the past 50 years (1905-1955), those of September 1938, September 1944 and August 1954, and a recurrence of the flood-producing storms and other hurricanes in this period, would result in a savings of $226,880,000, amounting annually to $4,538,000. Including scare cost elimination benefits, the annual savings would amount to $4,636,000. Substitution of the design storm for the hurricane of 1938 would result in a total 50-year savings of $309,960,000, or $6,199,000 annually, amounting to $6,297,000 with scare-cost benefits. Table 8 presents these recurring damages, the damages that would be prevented by the plan of protection and the damages that would remain in the bay area. These residual damages do not reflect wave action within the protected areas because available data do not permit reliable estimates of such damages.

TABLE 8

RECURRING AND PREVENTABLE TIDAL
FLOOD DAMAGES
(1956 Price Levels)

Narragansett Bay Area

Hurricane	Recurring Flood Damages	Damages Preventable by Plan	Residual Damages
September 21, 1938	$120,220,000	$120,010,000	$210,000
September 14, 1944	6,860,000	6,860,000	none
August 31, 1954 (Carol)	92,230,000	92,120,000	110,000
Other Hurricanes and Severe Storms (1905-1955)	7,890,000	7,890,000	None
Total	$227,200,000	$226,880,000	$320,000
Design Hurricane	$203,960,000	$203,090,000	$870,000

69. UNEVALUATED TANGIBLE BENEFITS

The planned protection of the Narragansett Bay area would result in additional important benefits which have not been monetarily evaluated. Substantial benefits would stem from the prevention of tangible damage to transient items such as vessels afloat and vehicles parked on streets or in parking lots. Benefits would also be realized from the reduction of intangible losses, including loss of life, health, and the threat to national security. Refer to Appendix D for a detailed discussion of the derivation of annual losses and benefits.

70. INTANGIBLE BENEFITS

Intangible benefits loom large in the total benefits to be derived from the construction of proposed barriers. Loss of life would be prevented. Dangers of disease arising from polluted flood waters and water supplies would be eliminated. Insecurity and worry among the residents concerning unpredictable hurricane flooding causing loss of life and property would no longer be a concern. Protection would stimulate all segments of the economy and improve the general welfare of the residents. With vital Naval interests in the area, the plan would significantly contribute to the national defense.

ECONOMIC JUSTIFICATION

71. BENEFIT-COST COMPARISON

The Fox Point barrier, the first unit to be constructed, would have a benefit-cost ratio of 2.37 to 1.0. The benefit-cost ratio for the Lower Bay barriers would range from 1.65 to 1.0 to 1.02 to 1.0. These ratios correspond to the range of first cost of the Lower Bay barriers from $69,000,000 to $109,000,000. Average annual benefits of the two-unit plan are estimated at $6,000,000. The benefit-cost ratio for the plan as a whole ranges from 1.22 to 1.0 to 1.81 to 1.0, as summarized in Table 9.

From another viewpoint, benefits of approximately $203,000,000 that would be attributable to the two-unit plan from one design hurricane flood would more than pay for construction of the project. Of the total, $78,000,000 would accrue to the Fox Point barrier and the remaining $125,000,000 to the Lower Bay barriers.

TABLE 9

ECONOMIC DATA OF PROPOSED PLAN,
NARRAGANSETT BAY AREA
(1956 price levels)

Unit	Average Annual Benefits	Average Annual Charges Minimum	Average Annual Charges Maximum	Benefit-Cost Ratio Lower Limit	Benefit-Cost Ratio Upper Limit
Fox Point Barrier	$1,733,000	$ 732,000	$ 732,000	2.37:1.0	2.37:1.0
Lower Bay Barriers	4,267,000	2,580,000	4,167,000	1.02:1.0	1.65:1.0
Total	$6,000,000	$3,312,000	$4,899,000	1.22:1.0	1.81:1.0

PROPOSED LOCAL COOPERATION

72. Officials of the State of Rhode Island at the public hearing on 1 October 1956 expressed the view that policies for Federal financing of flood control projects should be applied to hurricane flood protection projects, and have indicated their willingness to participate on this basis in paying such costs as land acquisitions, changes in local facilities and maintenance.

Small boats wrecked at Barrington, Rhode Island, in Hurricane of September 1938. Small-boat damage, amounting to about $5, 000, 000, occurred during Hurricane "Carol" (August 1954).

Photo by Max Muller

The Fox Point barrier, which would protect the business center of Providence, is presented as a local protection project with construction by the Federal government and operation and maintenance by the city. On this basis, local interests would be required to participate as follows:

a. Provide without cost to the United States all lands, easements and rights-of-way necessary for the construction of the project. The cost has been estimated at $200,000.

b. Provide without cost to the United States all relocations of buildings and utilities, sewers and related facilities. The cost has been estimated at $120,000.

c. Hold and save the United States free from damages due to the construction works.

d. Maintain and operate all works after completion in accordance with regulations prescribed by the Secretary of the Army. Maintenance and operation have been estimated to be $134,000 annually, the present worth of which amounts to $3,800,000 over the 50-year amortization period.

The Lower Bay barriers, consisting of the East, West and Tiverton barriers, would protect several cities and many towns in two states and also large Naval installations. Navigation, fisheries and pollution control would be affected. The project would be constructed, operated and maintained by the Federal government. Cost of operation and maintenance would be borne by local interests. Benefits would be largely general, accruing to a diversity of interests in the region. Local interests would be required to participate as follows:

a. Provide without cost to the United States all lands, easements and rights-of-way necessary for the construction of the project. The cost has been estimated at $110,000.

b. Hold and save the United States free from damages due to the construction works. No cost estimate is available, but it is possible that this could be a substantial item considering interests of the fishing industry, pollution control and navigation.

c. Contribute in cash to the first cost of the barriers a sum in lieu of annual operation and maintenance. This contribution is estimated to range from $1,617,000 to $3,687,000, depending on the final design. The annual cost of operation and maintenance

is estimated to range from $57,000 to $130,000. As an alternative, local interests could contract to pay annually the cost to the United States for the performance of this work.

APPORTIONMENT OF COSTS AMONG INTERESTS

73. A breakdown of the total first cost and annual charges for the plan of protection between Federal and local interests, based on local protection to the extent set forth in paragraph 72, above, is shown in Tables 5, 6, and 7.

The total first cost of the Fox Point barrier is $16,500,000. Local costs are $200,000 for lands and rights-of-way and $120,000 for modifications of sewers and drainage, a total of $320,000, leaving a Federal first cost of $16,180,000. The local cost of operation and maintenance is estimated at $134,000.

The total first cost of the Lower Bay barriers is estimated to range between $69,000,000 and $109,000,000, depending on the final design. This includes local costs estimated at $110,000 for the acquisition of lands and rights-of-way, and a cash contribution by local interests toward the first cost of the project ranging between $1,617,000 and $3,687,000, giving a total local first cost of $1,730,000 to $3,800,000. The Federal first cost becomes $67,270,000 to $105,200,000.

COORDINATION WITH OTHER AGENCIES

74. The study has been coordinated with various Federal, state and local agencies, who were contacted for the purpose of either furnishing technical data or cooperating with the Corps of Engineers in those phases of the study where mutual responsibilities and interests were involved. The contributions of the agencies involved and a summary of their views, where views were expressed regarding the proposed plan of protection are discussed below.

a. Federal agencies. The Weather Bureau of the Department of Commerce has made comprehensive studies of the behavior and characteristics of past hurricanes and has determined the maximum wind velocities and durations to be expected in future storms. The Public Health Service of the Department of Health, Education and Welfare is studying the effect of Lower Bay barriers on pollution and pollution control. A preliminary evaluation suggests that the reduction in tidal range created by the barriers would have no effect on the overall quality of the water in the bay, but might have some local adverse effects unless adequate treatment is provided.

The Fish and Wildlife Service of the Department of the Interior has been making a continuing study of the effect of the Lower Bay barriers on the fisheries resources of the bay. Because the fishing industry is an important source of revenue in Rhode Island, the total annual commercial catch amounting to nearly $5,000,000 and the total sport fishery to about $3,000,000 at present, a systematic long-range program of studies, scheduled for completion in October 1958, is in progress to evaluate any changes in the fisheries resources that may arise from construction of barriers.

Plans for hurricane protection were closely coordinated with the Department of the Navy in view of the extensive Naval installations in Narragansett Bay. The Department of the Navy has indicated that the proposed opening in the East barrier is not satisfactory and alternative openings are being considered. Other Federal agencies contacted were the Geological Survey of the Department of the Interior, the Coast Guard of the Department of the Treasury, and the Coast and Geodetic Survey and Bureau of Public Works of the Department of Commerce. The work of all the other Federal agencies concerned is continuing in order that the Lower Bay barriers may be improved to minimize any adverse effects on present conditions in the bay.

b. State agencies. In Massachusetts, the Governor has expressed approval of the plan for the Departments of Commerce, Public Works, Public Health, and Natural Resources and urged more detailed studies of possible effects of the project on pollution and fisheries (see Appendix G). In Rhode Island, close coordination was maintained with the Departments of Public Works, Health, and Agriculture and Conservation as well as the Rhode Island Development Council. Officials have approved the plan subject to further studies of the effect of the Lower Bay barriers on fisheries and natural conditions. The Department of Health has stated that the Lower Bay plan would make pollution control more difficult and urged consideration of barriers that would not produce a significant change in the tidal prism. The Narragansett Marine Laboratory of the University of Rhode Island was of particular assistance in collecting existing data, making new surveys of the hydrography and oceanography of Narragansett Bay, and carrying out analytical studies of the physical variables in the bay. The Governor of Rhode Island's Hurricane Survey Advisory Committee, composed of representatives of Rhode Island communities throughout the Narragansett Bay area, assisted and advised the Corps of Engineers of local views and desires. It endorsed the two-unit plan of protection but requested additional studies of the effects of the Lower Bay barriers on fish and wildlife, pollution and navigation.

c. Local agencies. The Hurricane Protection Committee of the Mayor of Providence was of great assistance in studies of proposals for the protection of Providence against hurricane flooding. The Narragansett Electric Company, a public utility with two steam-electric generating plants along the Providence River in Providence, cooperated closely in studies of the Fox Point Barrier. Comments were obtained from the American Merchant Marine Institute and the Rhode Island Pilots Association, two organizations concerned with the effects of the plan on navigation.

DISCUSSION

75. THE PROBLEM

The Narragansett Bay area has experienced very heavy tidal flood losses in recent hurricanes owing to its exposure to the Atlantic Ocean on the south. Hurricane tidal surges are funnelled into the bay and flood densely populated and developed areas, especially in the vicinity of Providence, Newport and Fall River. Recurring flood losses are estimated at approximately $120,000,000 for the September 1938 hurricane; $7,000,000 for the September 1944 hurricane, which struck at low tide; and $92,000,000 for the August 1954 hurricane. Loss of life has been great, with over 250 lives lost in Narragansett Bay and along the Rhode Island coast during the 1938 and 1954 hurricanes. The need for protection has become urgent, particularly in Providence, the capital city and chief commercial center of Rhode Island where a recurrence of the 1938 flood would cause over $40,000,000 damages. Since a repetition of the hurricane floods of the last 20 years would cause damages totalling approximately $220,000,000, at 1956 price levels, it is obvious that protective measures are needed to safeguard the areas subject to tidal flooding against future attacks.

A design flood, derived by transposing the 1944 hurricane, a storm of unusual energy off Cape Hatteras, to a track over water and timed to strike at high tide in Narragansett Bay, is capable of causing about $204,000,000 of damage.

76. SOLUTIONS CONSIDERED

Hurricane warnings and evacuation measures, although effective in reducing the loss of life and damage to items which may be moved, have relatively little value in preventing property damage. The cost of permanent relocation of buildings and rezoning of areas subject to tidal flooding would be prohibitive because the valuation of the property involved is many times the cost of protection or the amount of damages. Moreover, any extensive relocation would disrupt the entire economy of the area. Hence, a more positive means of protection which will eliminate the threat of future flooding to existing properties is required.

Studies indicate that tidal flood barriers are the most practicable means of assuring general protection. Though costly, such barriers can provide a high degree of protection for large extents of the 250-mile bay shoreline. Protective structures for individual localities prove economically unjustified except in concentrated high valuation areas.

17. SELECTION OF PLAN

Four alternative barrier plans of protection were considered:

a. Lower Bay barriers: A plan of barriers, with navigational openings, across the three entrances to Narragansett Bay.

b. Middle Bay barriers: A plan of barriers, with navigational openings, across the Middle Bay using the islands as stepping stones.

c. Fields Point barrier: A plan for a barrier, with a pumping station and navigational opening, at Fields Point in Providence.

d. Fox Point barrier: A plan for a barrier, with sluice gates and a pumping station, at Fox Point in Providence.

Selection of the most feasible and beneficial scheme was resolved by means of detail study and analysis supplemented by information obtained from operation of a large scale model of Narragansett Bay upon which surge and tidal conditions were induced. The model tests indicated that build-up would occur below barriers located at the Middle Bay or Fields Point sites and would result in substantial increases in flooding in these unprotected areas. The Fields Point site was further handicapped by the need of extremely large pumping equipment for discharging the fresh water flows of the Blackstone River. For these reasons, the Middle Bay and Fields Point plans were discarded.

The Lower Bay plan by itself can provide a large degree of protection throughout the entire bay. The protection is in the form of reduced flood levels and will vary with the size of the navigation opening constructed. Reduction of water levels provides a high degree of protection in the Lower Bay area, but in the upper bay, water level reduction would be less and residual damages would still remain. The design and construction of Lower Bay barriers is without precedent and many complex problems are involved. Barriers with openings small enough to provide complete protection against hurricane flooding would restrict the movement of commercial and naval vessels and possibly affect the bay fisheries, pollution conditions and recreation. Several years will be required to resolve the navigation, pollution and fisheries problems and borings must be obtained before sufficient information on the foundation will be available to permit the final design of the structures.

The Fox Point barrier would provide virtually complete protection against hurricane tidal flooding for the major portion of the City of Providence. The barriers would protect the downtown area where 35 percent of the total experienced damage in the Bay has occurred. This barrier would have no adverse effects on tidal action and could be designed and constructed in a relatively short period of time. With the long period of time required to resolve the problems, prepare the design, and construct the Lower Bay barrier, the relatively short period required to put the Fox Point barrier in operation and the urgent need for protection in downtown Providence, the Fox Point barrier should be constructed first. Installation of the two barrier units would provide a very high degree of protection against hurricane flooding and leave only isolated locations subject to wave damage. Studies are underway to determine what measures can be provided for these locations and will be the subject of another report.

78. COSTS AND BENEFITS

The combined plan would prevent damages amounting to approximately $203,000,000 in a design flood 2 to 3 feet higher than the record flood of 1938. The first unit to be constructed, Fox Point barrier costing $16,500,000, would prevent $78,000,000 of this damage.

Average annual benefits are:

Combined plan	$6,000,000
Fox Point	$1,733,000
Lower Bay	$4,267,000

Annual costs are:	Lower limit		Upper limit
Combined plan	$3,312,000	to	$4,899,000
Fox Point	$ 732,000		$ 732,000
Lower Bay	$2,580,000	to	$4,167,000

Benefit-cost ratios are:	Lower limit	Upper limit
Combined plan	1.81 to 1.0	1.22 to 1.0
Fox Point	2.37 to 1.0	2.37 to 1.0
Lower Bay	1.65 to 1.0	1.02 to 1.0

CONCLUSIONS

79. From the foregoing analyses of basic data and engineering studies made with the assistance of the Waterways Experiment Station, Beach Erosion Board, Weather Bureau and other agencies, it is concluded that:

a. Devastating tidal floods occur in Narragansett Bay due to its exposed location in the path of tropical hurricanes and the peculiar physical features of the bay and approaches.

b. The flood problem has become acute because of three recent major hurricane floods. These took over 250 lives in the bay and on the Rhode Island coast. A repetition of these floods would cost about $220,000,000.

c. A future flood may exceed recent floods by three feet and reach elevations up to 19 feet above mean sea level at Providence. Total damages of $204,000,000 would result.

d. The only practical means of protection is by tidal flood barriers. Flood warnings, zoning and evacuation of flood areas and local walls and dikes have limited application.

e. Tidal flood barriers should be restricted to locations in the Lower Bay or close to the headwaters. Barriers at intermediate points would increase down-bay flooding.

f. The most feasible plan of protection is the combination of (1) a single barrier at the head of the Providence River (Fox Point barrier), and (2) barriers, with navigation openings, across the three entrances to the bay (Lower Bay barriers).

g. The Fox Point barrier is urgently needed and should be constructed immediately.

h. The Lower Bay barriers are needed to protect the bay as a whole. They restrict the in and out movement of ocean tides and affect:

(1) Passage of naval vessels.

(2) Water quality and flushing of pollutants.

(3) Fisheries and recreation.

These problems, which must be resolved prior to construction, will require additional investigation, extensive studies and hydraulic model tests.

i. One great flood would pay for the Fox Point project cost several times over; a very real threat in the period of years required for solution of the very difficult problems, design, and construction of the Lower Bay barriers.

RECOMMENDATIONS

80. It is recommended that a two-unit plan for hurricane protection in Narragansett Bay be authorized for construction as follows:

a. A barrier and accessories at Fox Point, as described in paragraph 57. The total estimated first cost of the Fox Point barrier is $16,500,000, to be borne jointly by the United States and local interests. The estimated cost to the United States would be $16,180,000.

b. A series of Lower Bay barriers in the East Passage, West Passage, and Sakonnet River as described in paragraph 58, subject to further studies of foundation conditions and satisfactory resolution of the following problems:

(1) Agreement with the Department of the Navy on acceptable navigation openings.

(2) Adverse effects on water quality and pollution in the Bay.

(3) Adjustment of possible adverse effects on fish and wildlife and recreation in the Bay.

The total first cost of the Lower Bay barriers is estimated to range between $69,000,000 and $109,000,000 depending on the final design of the navigation openings, sluice gates, and foundation. The first cost would be borne jointly by the United States and local interests, with the cost to the United States ranging between $67,273,000 and $105,203,000.

c. Construction be subject to the condition that local interests participate as follows:

(1) Provide without cost to the United States all lands, easements and rights-of-way necessary for the construction of the project.

(2) Provide without cost to the United States all relocations of buildings and utilities, sewers, roads and related facilities.

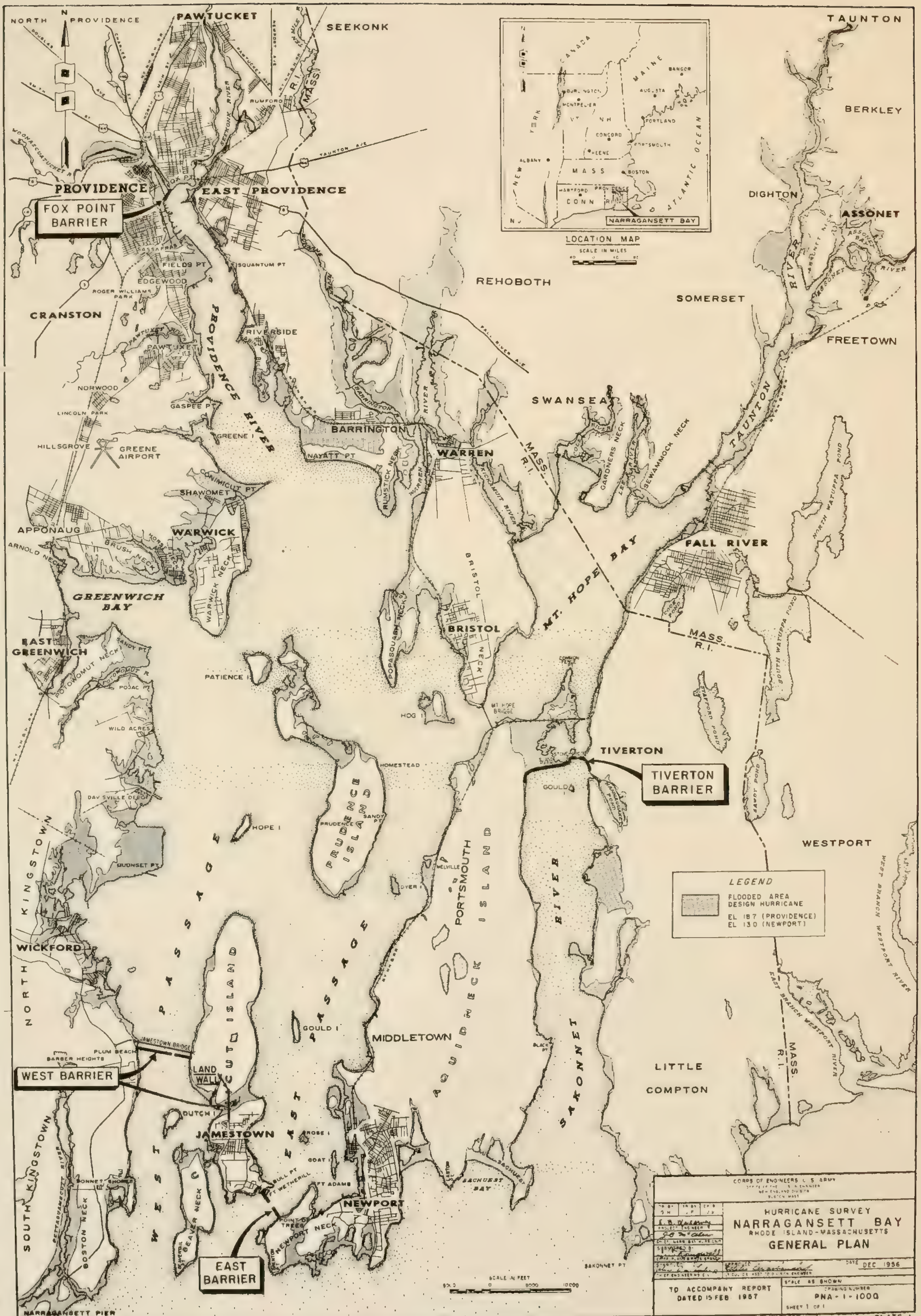
(3) Hold and save the United States free from damages due to the construction works.

(4) Maintain and operate the Fox Point barrier after completion in accordance with regulations prescribed by the Secretary of the Army. The annual cost of operation and maintenance is estimated at $134,000.

(5) Contribute to the first cost of the Lower Bay barriers a sum in lieu of annual operation and maintenance. Such contribution is estimated to range from $1,617,000 to $3,687,000 depending on the final design.

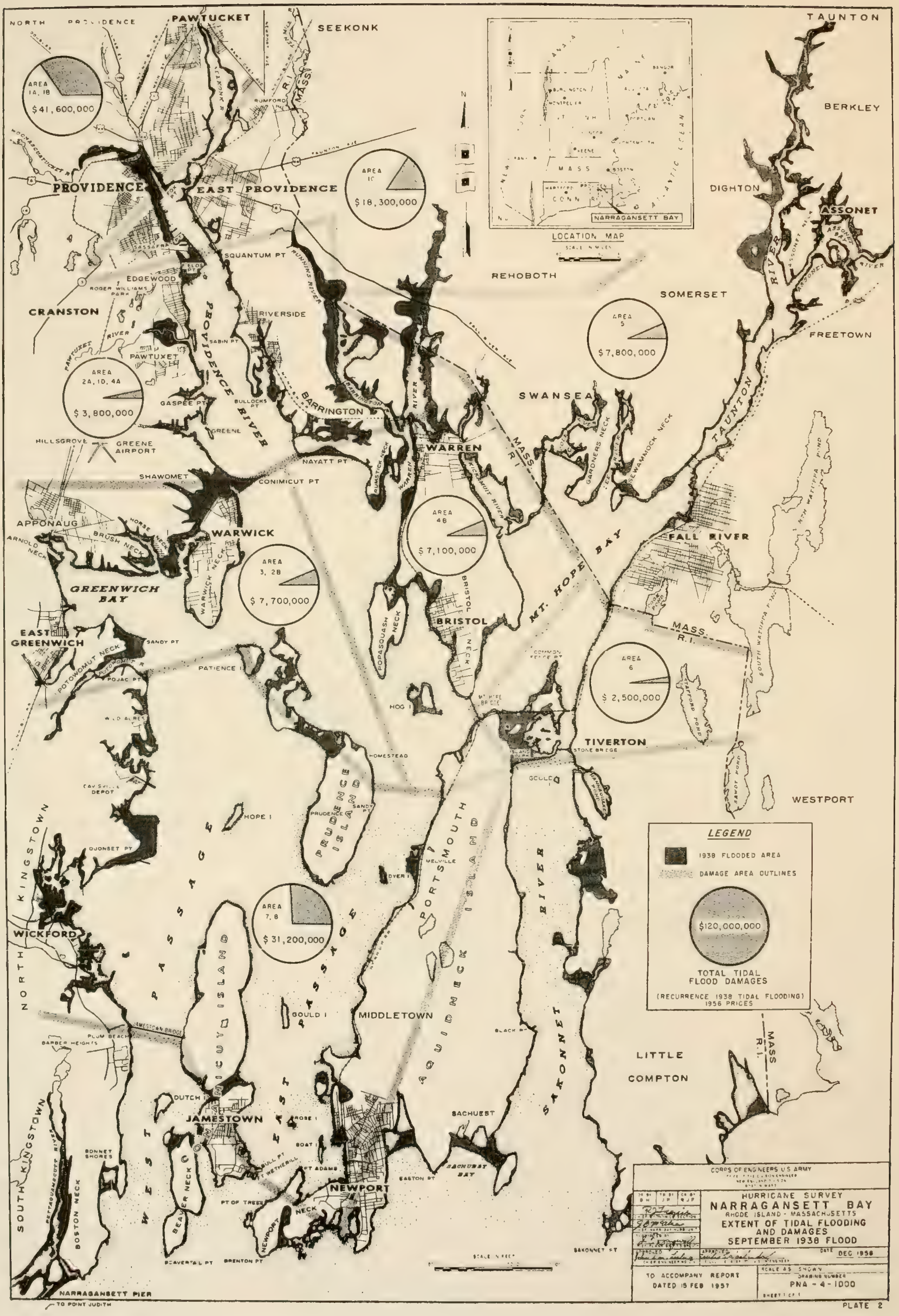
ROBERT J. FLEMING, JR.
Brigadier General, U.S. Army
Division Engineer

Inclosures
9 Plates
1. General Plan
2. Extent of Tidal Flooding and Damages. Sept. 1938 Flood
3. Fox Point Barrier Plan.
4. Fox Point Barrier Plan, Plan Profile and Sections
5. Lower Bay Barrier Plan. East Barrier, Conanicut Island to Newport Neck
6. Lower Bay Barrier Plan. West Barrier, Plum Beach to Conanicut Island
7. Lower Bay Barrier Plan. Tiverton Barrier. Portsmouth to Tiverton
8. Narragansett Bay. Hurricane Flood Levels. Sept. 1938 Flood Reduced by Fox Point and Lower Bay Barriers
9. Mt. Hope Bay - Sakonnet River. Hurricane Flood Levels. Sept. 1938 Flood Reduced by Lower Bay Barriers



LOCATION MAP
SCALE IN MILES
NARRAGANSETT BAY
LEGEND
FLOODED AREA
DESIGN HURRICANE
EL 18.7 (PROVIDENCE)
EL 13.0 (NEWPORT)
FOX POINT BARRIER
TIVERTON BARRIER
WEST BARRIER
EAST BARRIER
LAND WALL
PROVIDENCE
EAST PROVIDENCE
PAWTUCKET
CRANSTON
WARWICK
BARRINGTON
WARREN
BRISTOL
FALL RIVER
TIVERTON
NEWPORT
JAMESTOWN
MIDDLETOWN
WICKFORD
EAST GREENWICH
PROVIDENCE RIVER
MT. HOPE BAY
GREENWICH BAY
WEST PASSAGE
EAST PASSAGE
SAKONNET RIVER
TAUNTON RIVER
CORPS OF ENGINEERS U. S. ARMY
HURRICANE SURVEY
NARRAGANSETT BAY
RHODE ISLAND-MASSACHUSETTS
GENERAL PLAN
DEC 1956
TO ACCOMPANY REPORT DATED 15 FEB 1957
SCALE AS SHOWN
PNA - 1 - 1000
SHEET 1 OF 1

PLATE I



LEGEND
1938 FLOODED AREA
DAMAGE AREA OUTLINES
$120,000,000
TOTAL TIDAL FLOOD DAMAGES
(RECURRENCE 1938 TIDAL FLOODING)
1956 PRICES
AREA 1A, 1B $41,600,000
AREA 1C $18,300,000
AREA 2A, 1D, 4A $3,800,000
AREA 3, 2B $7,700,000
AREA 4B $7,100,000
AREA 5 $7,800,000
AREA 6 $2,500,000
AREA 7, 8 $31,200,000
LOCATION MAP
NARRAGANSETT BAY
PROVIDENCE
EAST PROVIDENCE
PAWTUCKET
NORTH PROVIDENCE
SEEKONK
REHOBOTH
CRANSTON
EDGEWOOD
PAWTUXET
WARWICK
APPONAUG
GREENWICH BAY
EAST GREENWICH
BARRINGTON
WARREN
BRISTOL
SWANSEA
SOMERSET
DIGHTON
BERKLEY
TAUNTON
ASSONET
FREETOWN
FALL RIVER
TIVERTON
WESTPORT
LITTLE COMPTON
MIDDLETOWN
PORTSMOUTH
NEWPORT
JAMESTOWN
WICKFORD
NORTH KINGSTOWN
SOUTH KINGSTOWN
PROVIDENCE RIVER
TAUNTON RIVER
MT. HOPE BAY
SAKONNET RIVER
WEST PASSAGE
EAST PASSAGE
PRUDENCE ISLAND
CONANICUT ISLAND
AQUIDNECK ISLAND
MASS. R.I.
NARRAGANSETT PIER
TO POINT JUDITH
CORPS OF ENGINEERS U.S. ARMY
HURRICANE SURVEY
NARRAGANSETT BAY
RHODE ISLAND - MASSACHUSETTS
EXTENT OF TIDAL FLOODING AND DAMAGES
SEPTEMBER 1938 FLOOD
DEC 1956
SCALE AS SHOWN
PNA - 4 - 1000
TO ACCOMPANY REPORT DATED 15 FEB 1957

PLATE 2

CORPS OF ENGINEERS U. S. ARMY

LOCATION MAP

SCALE IN MILES

FOX POINT BARRIER PLAN

SCALE IN FEET

400 0 400 800 1200 1600

CORPS OF ENGINEERS U S ARMY
OFFICE OF THE DIVISION ENGINEER
NEW ENGLAND DIVISION
BOSTON MASS

DR BY H A	TR BY J P	CK BY C W

E. B. Macauley
PROJECT ENGINEER

CHIEF, NARR BAY HURR UNIT

SUBMITTED BY
CHIEF PLANS AND REP'TS BRANCH

APPROVED
CHIEF ENGINEERING DIV

APPROVED
LT COL C E ASST TO DIVISION ENGINEER

HURRICANE SURVEY
NARRAGANSETT BAY
RHODE ISLAND
FOX POINT BARRIER PLAN
PROVIDENCE RIVER RHODE ISLAND

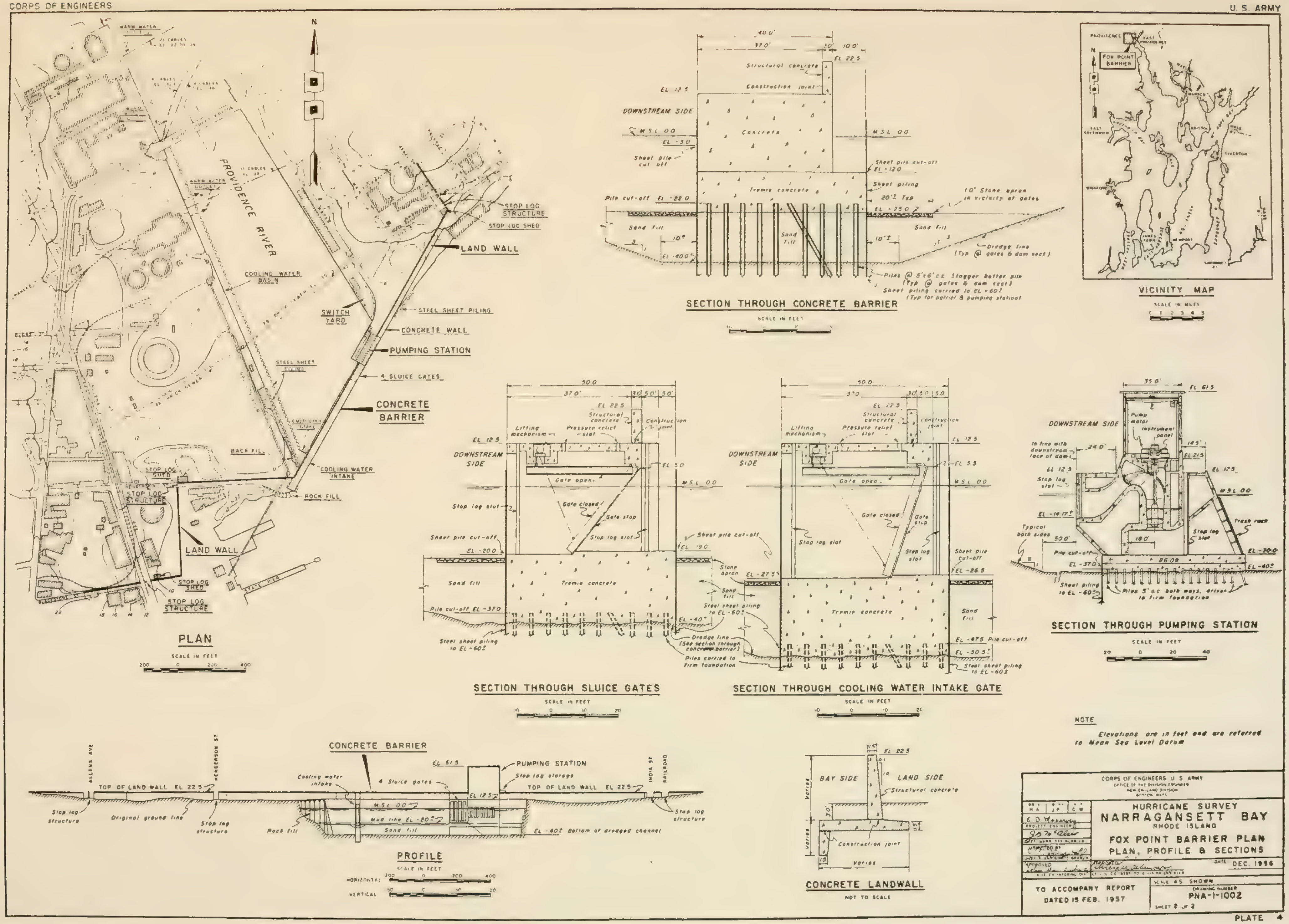
DATE DEC 1956

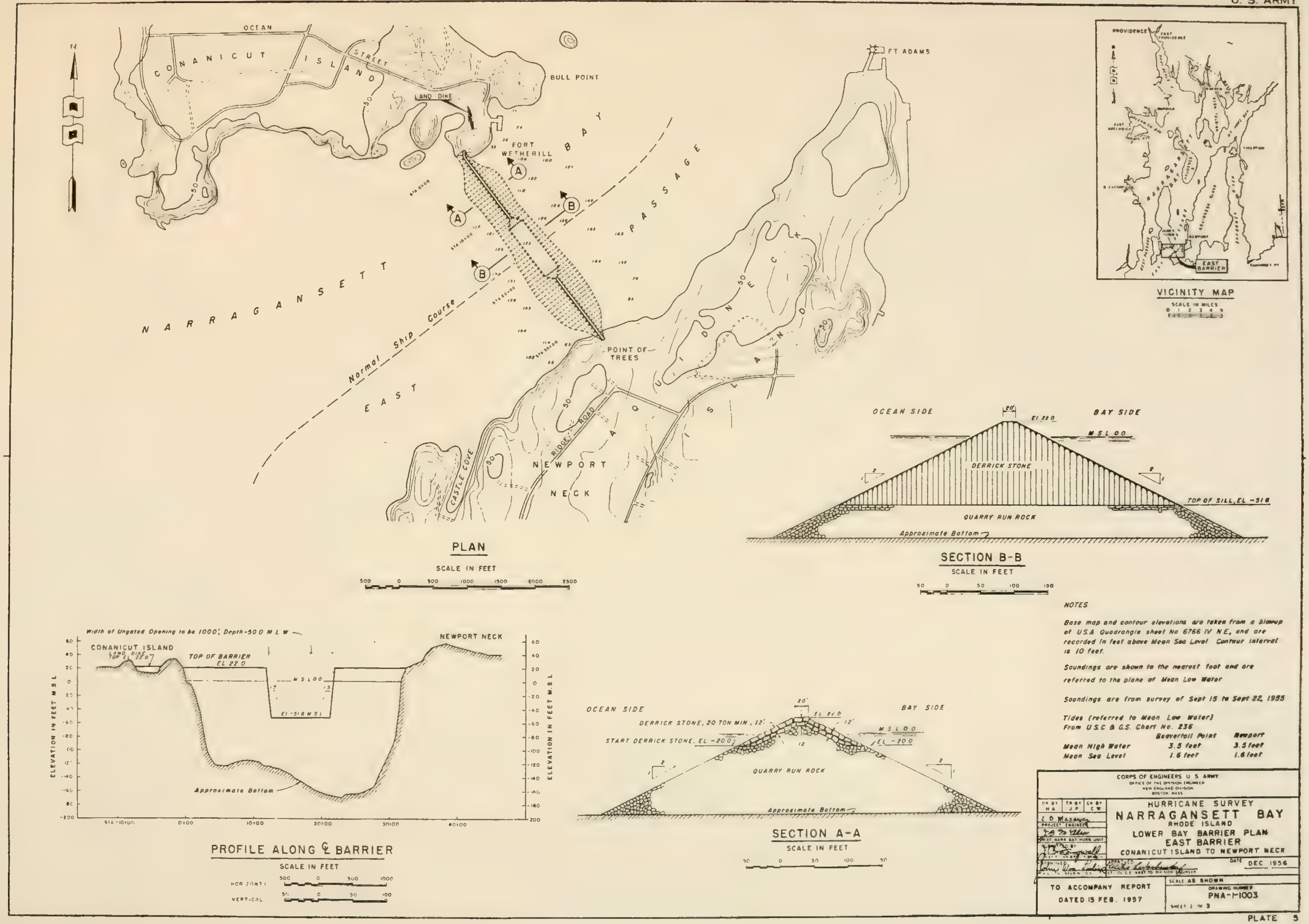
SCALE AS SHOWN

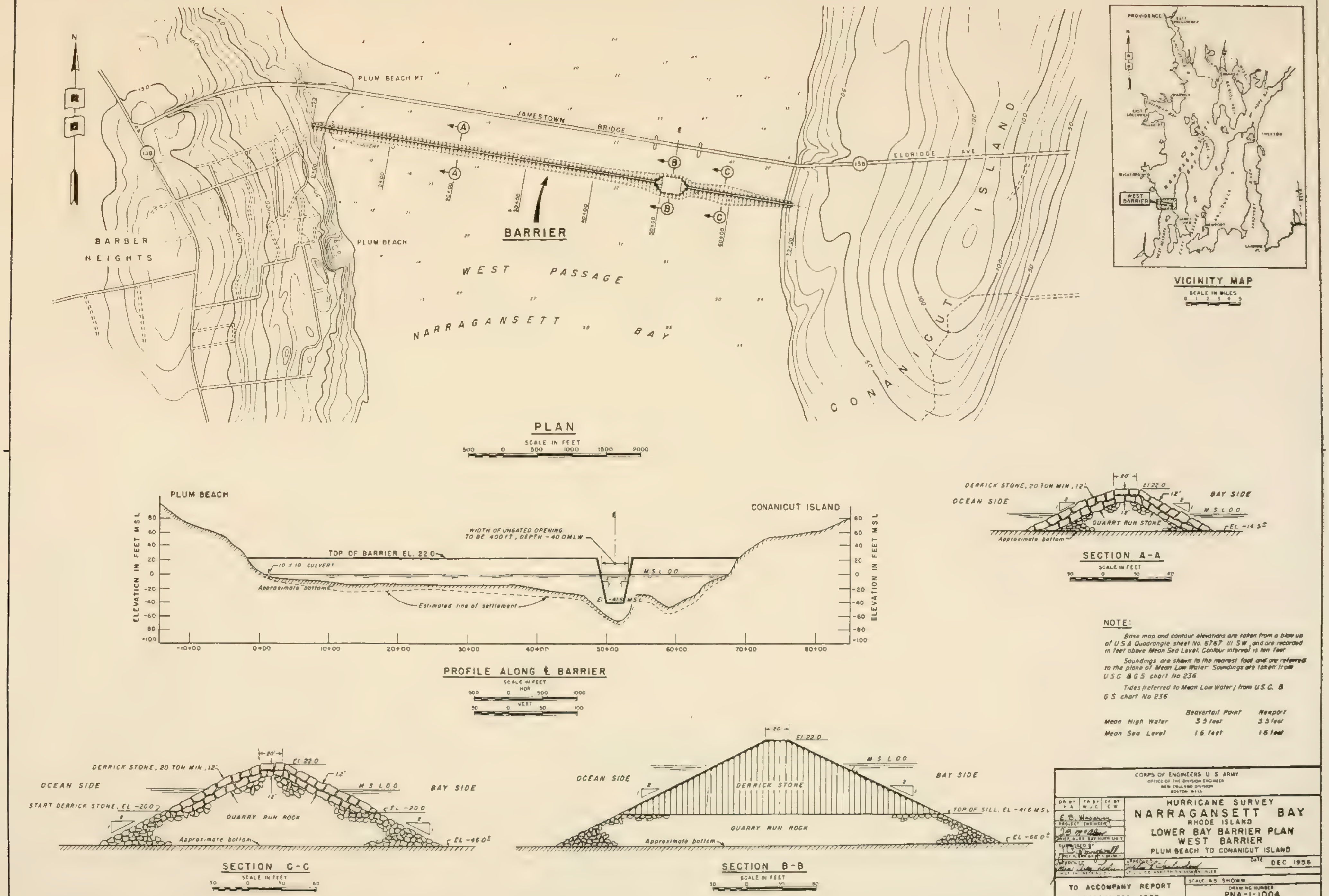
DRAWING NUMBER PNA-1-1001

SHEET 1 OF 2

TO ACCOMPANY REPORT DATED 15 FEB 1957


PLAN
SCALE IN FEET
PROVIDENCE RIVER
STOP LOG STRUCTURE
STOP LOG SHED
LAND WALL
COOLING WATER BASIN
SWITCH YARD
STEEL SHEET PILING
CONCRETE WALL
PUMPING STATION
4 SLUICE GATES
CONCRETE BARRIER
BACK FILL
COOLING WATER INTAKE
ROCK FILL
SECTION THROUGH CONCRETE BARRIER
SCALE IN FEET
Structural concrete
Construction joint
DOWNSTREAM SIDE
Concrete
Tremie concrete
Sheet pile cut off
Sheet piling
10' Stone apron in vicinity of gates
Sand fill
Dredge line (Typ @ gates & dam sect)
Piles @ 5'x6' c.c. Stagger batter pile (Typ @ gates & dam sect.)
Sheet piling carried to EL -60± (Typ for barrier & pumping station)
VICINITY MAP
SCALE IN MILES
PROVIDENCE
EAST PROVIDENCE
FOX POINT BARRIER
SECTION THROUGH SLUICE GATES
SCALE IN FEET
Lifting mechanism
Pressure relief slot
Gate open
Gate closed
Gate stop
Stop log slot
Sheet pile cut-off
Stone apron
Sand fill
Steel sheet piling to EL -60±
Dredge line (See section through concrete barrier)
Piles carried to firm foundation
SECTION THROUGH COOLING WATER INTAKE GATE
SCALE IN FEET
SECTION THROUGH PUMPING STATION
SCALE IN FEET
Pump motor
Instrument panel
In line with downstream face of dam
Trash rack
Typical both sides
Sheet piling to EL -60±
Piles 5' c.c. both ways, driven to firm foundation
NOTE
Elevations are in feet and are referred to Mean Sea Level Datum
CONCRETE BARRIER
PUMPING STATION
Cooling water intake
4 Sluice gates
Stop log storage
TOP OF LAND WALL EL 22.5
Stop log structure
Original ground line
Rock fill
Sand fill
Mud line EL -20±
EL -40± Bottom of dredged channel
ALLENS AVE
HENDERSON ST
INDIA ST
RAILROAD
PROFILE
SCALE IN FEET
HORIZONTAL
VERTICAL
CONCRETE LANDWALL
NOT TO SCALE
BAY SIDE
LAND SIDE
Structural concrete
Construction joint
Varies
CORPS OF ENGINEERS U.S. ARMY
OFFICE OF THE DIVISION ENGINEER
NEW ENGLAND DIVISION
BOSTON, MASS.
HURRICANE SURVEY
NARRAGANSETT BAY
RHODE ISLAND
FOX POINT BARRIER PLAN
PLAN, PROFILE & SECTIONS
DEC. 1956
SCALE AS SHOWN
TO ACCOMPANY REPORT DATED 15 FEB. 1957
DRAWING NUMBER
PNA-1-1002
SHEET 2 of 2


OCEAN
CONANICUT ISLAND
STREET
BULL POINT
LAND DIKE
FORT WETHERILL
BAY
FT ADAMS
EAST PASSAGE
NARRAGANSETT
Normal Ship Course
POINT OF TREES
AQUIDNECK ISLAND
RIDGE ROAD
CASTLE COVE
NEWPORT NECK
PLAN
SCALE IN FEET
500 0 500 1000 1500 2000 2500
VICINITY MAP
SCALE IN MILES
PROVIDENCE
EAST BARRIER
OCEAN SIDE
BAY SIDE
20'
EL 22.0
M S L 0.0
DERRICK STONE
QUARRY RUN ROCK
TOP OF SILL, EL -51.6
Approximate Bottom
SECTION B-B
SCALE IN FEET
50 0 50 100 150
Width of Ungated Opening to be 1000', Depth -50.0 M L W
CONANICUT ISLAND
LAND DIKE
TOP OF BARRIER EL 22.0
NEWPORT NECK
M S L 0.0
EL -51.6 M S L
Approximate Bottom
ELEVATION IN FEET M.S.L
PROFILE ALONG ℄ BARRIER
SCALE IN FEET
HORIZONTAL 500 0 500 1000
VERTICAL 50 0 50 100
OCEAN SIDE
BAY SIDE
DERRICK STONE, 20 TON MIN., 12'
START DERRICK STONE, EL -20.0
EL 22.0
M S L 0.0
EL -20.0
QUARRY RUN ROCK
Approximate Bottom
SECTION A-A
SCALE IN FEET
50 0 50 100 150
NOTES
Base map and contour elevations are taken from a blowup of U.S.A Quadrangle sheet No 6766 IV N.E., and are recorded in feet above Mean Sea Level Contour interval is 10 feet.
Soundings are shown to the nearest foot and are referred to the plane of Mean Low Water
Soundings are from survey of Sept 15 to Sept 22, 1955
Tides (referred to Mean Low Water)
From U.S.C & G.S. Chart No. 236
Beavertail Point Newport
Mean High Water 3.5 feet 3.5 feet
Mean Sea Level 1.6 feet 1.6 feet
CORPS OF ENGINEERS U S ARMY
OFFICE OF THE DIVISION ENGINEER
NEW ENGLAND DIVISION
BOSTON MASS
HURRICANE SURVEY
NARRAGANSETT BAY
RHODE ISLAND
LOWER BAY BARRIER PLAN
EAST BARRIER
CONANICUT ISLAND TO NEWPORT NECK
DATE DEC 1956
PROJECT ENGINEER
APPROVED
SCALE AS SHOWN
DRAWING NUMBER
PNA-I-1003
SHEET 1 OF 3
TO ACCOMPANY REPORT
DATED 15 FEB. 1957



NOTE:

Base map and contour elevations are taken from a blow up of U S A Quadrangle sheet No. 6767 III S W, and are recorded in feet above Mean Sea Level. Contour interval is ten feet.

Soundings are shown to the nearest foot and are referred to the plane of Mean Low Water. Soundings are taken from U S C & G S chart No 236

Tides (referred to Mean Low Water) from U.S.C. & G S chart No 236

	Beavertail Point	Newport
Mean High Water	3.5 feet	3.5 feet
Mean Sea Level	1.6 feet	1.6 feet

CORPS OF ENGINEERS U S ARMY
OFFICE OF THE DIVISION ENGINEER
NEW ENGLAND DIVISION
BOSTON MASS

DR BY H A | TR BY W J C | CK BY C W

E. B. Hassey — PROJECT ENGINEER

HURRICANE SURVEY
NARRAGANSETT BAY
RHODE ISLAND
LOWER BAY BARRIER PLAN
WEST BARRIER
PLUM BEACH TO CONANICUT ISLAND

DATE DEC 1956

SUBMITTED BY

APPROVED

APPROVED

TO ACCOMPANY REPORT DATED 15 FEB. 1957

SCALE AS SHOWN

DRAWING NUMBER PNA-1-1004

SHEET 2 OF 3

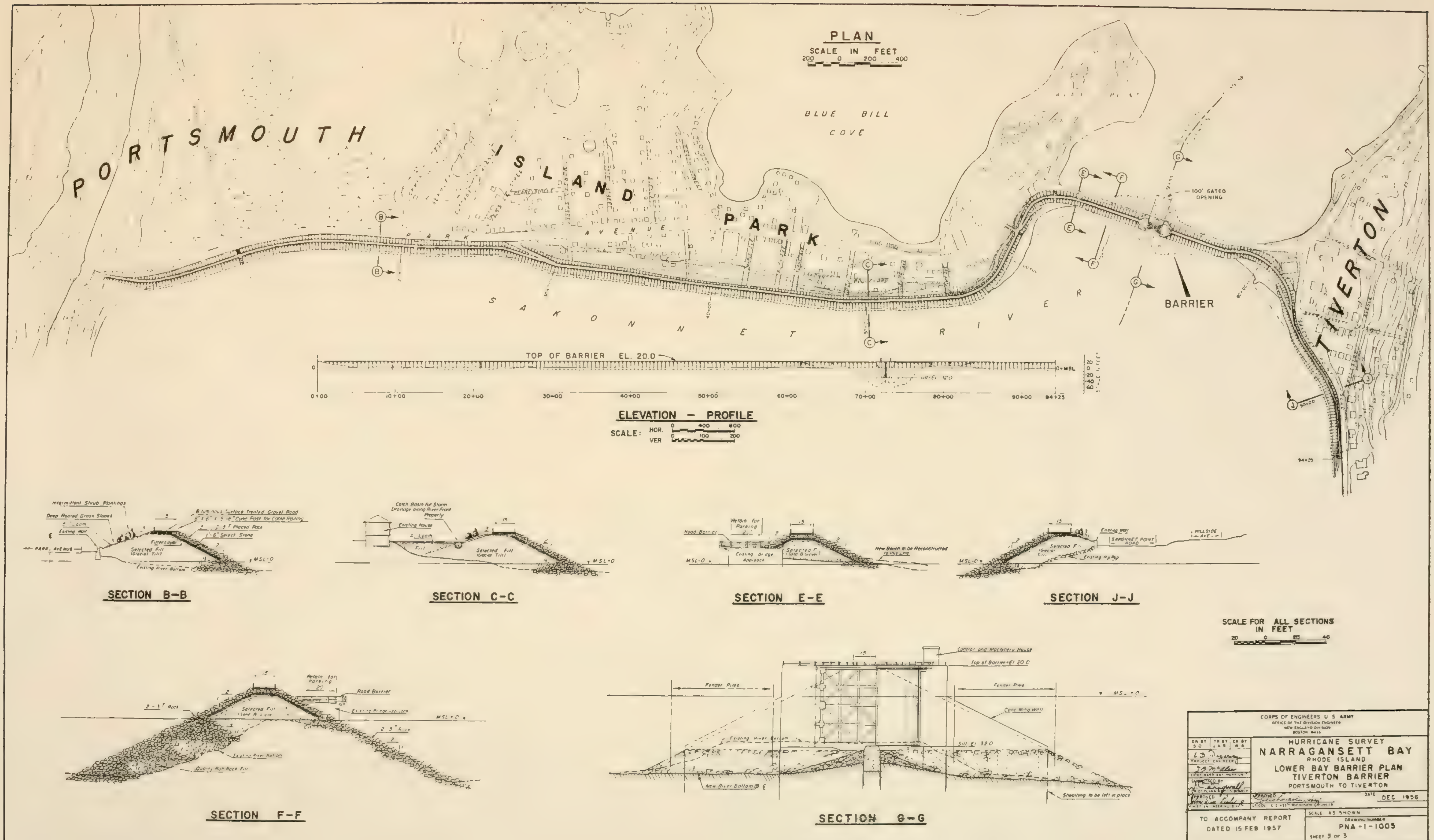
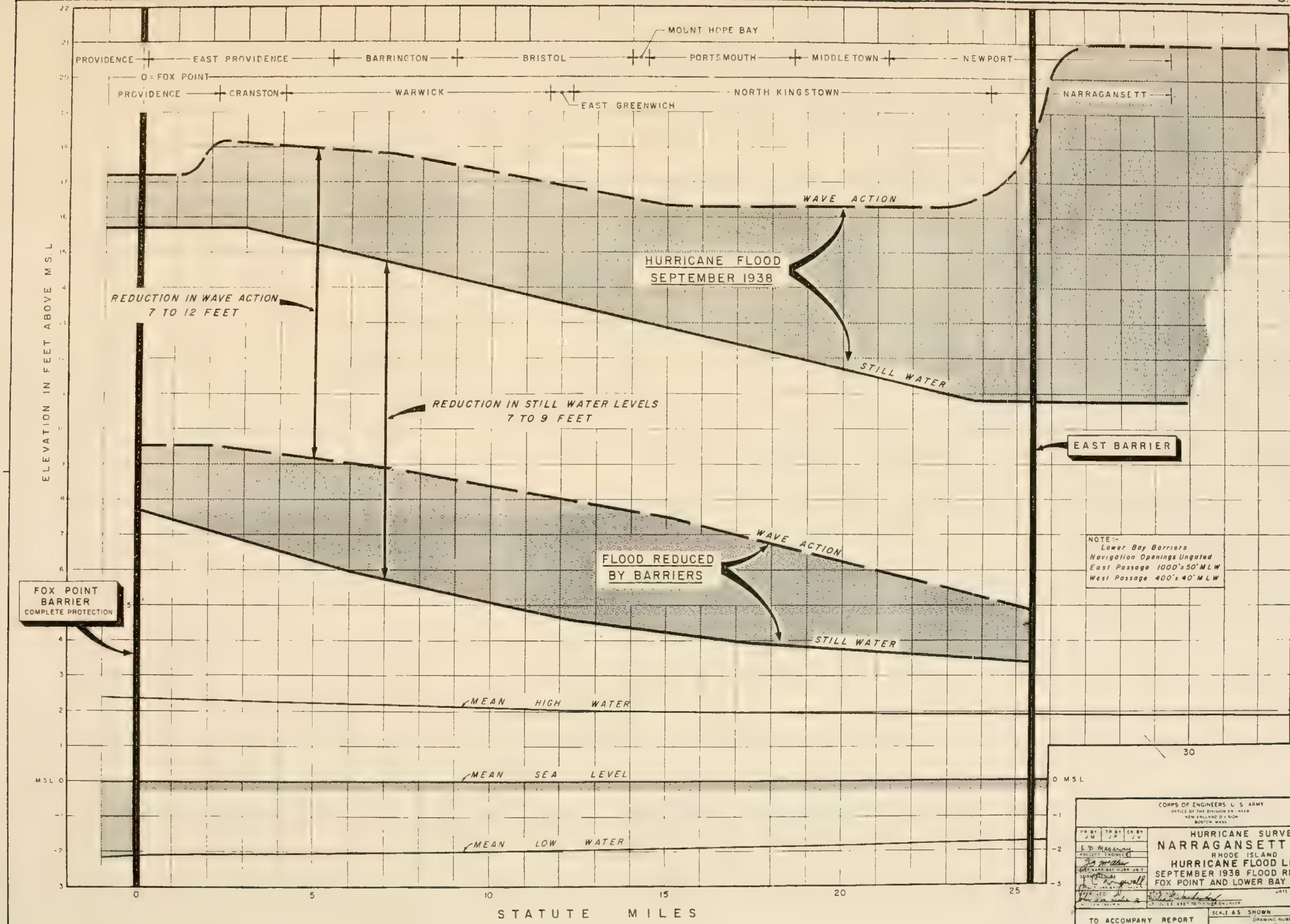

PLAN
SCALE IN FEET
200 0 200 400
BLUE BILL COVE
PORTSMOUTH
ISLAND PARK
PARK AVENUE
SAKONNET RIVER
100' GATED OPENING
BARRIER
TIVERTON
TOP OF BARRIER EL. 20.0
0+00
10+00
20+00
30+00
40+00
50+00
60+00
70+00
80+00
90+00
94+25
ELEVATION - PROFILE
SCALE: HOR. 0 400 800
VER. 0 100 200
Intermittent Shrub Plantings
Deep Rooted Grass Slopes
Selected Fill (Glacial Till)
Existing River Bottom
MSL-0
SECTION B-B
Catch Basin for Storm Drainage along River Front Property
Existing House
Selected Fill (Glacial Till)
MSL+0
SECTION C-C
Retain for Parking
New Beach to be Reconstructed
Existing Bridge Approach
SECTION E-E
Existing Wall
SAKONNET POINT ROAD
HILLSIDE AVE
SECTION J-J
SCALE FOR ALL SECTIONS IN FEET
20 0 20 40
Retain for Parking
Road Barrier
MSL+0
SECTION F-F
Control and Machinery House
Top of Barrier El 20.0
Fender Piles
Conc Wing Wall
Existing River Bottom
Sill El 32.0
New River Bottom
Shoaling to be left in place
SECTION G-G
CORPS OF ENGINEERS U S ARMY
OFFICE OF THE DIVISION ENGINEER
NEW ENGLAND DIVISION
BOSTON MASS
HURRICANE SURVEY
NARRAGANSETT BAY
RHODE ISLAND
LOWER BAY BARRIER PLAN
TIVERTON BARRIER
PORTSMOUTH TO TIVERTON
DATE DEC 1956
TO ACCOMPANY REPORT
DATED 15 FEB 1957
SCALE AS SHOWN
DRAWING NUMBER
PNA-1-1005
SHEET 3 OF 3

PLATE 7



CORPS OF ENGINEERS U. S. ARMY

HURRICANE SURVEY

NARRAGANSETT BAY

RHODE ISLAND

HURRICANE FLOOD LEVELS

SEPTEMBER 1938 FLOOD REDUCED BY FOX POINT AND LOWER BAY BARRIERS

DR BY J M | TR BY J P | CK BY J V

E. D. Meservey

PROJECT ENGINEER

DATE DEC. 1956

SCALE AS SHOWN

TO ACCOMPANY REPORT DATED 15 FEB 1957

DRAWING NUMBER PNA-3-1000

SHEET 1 OF 2

PLATE 8

CORPS OF ENGINEERS

U. S. ARMY

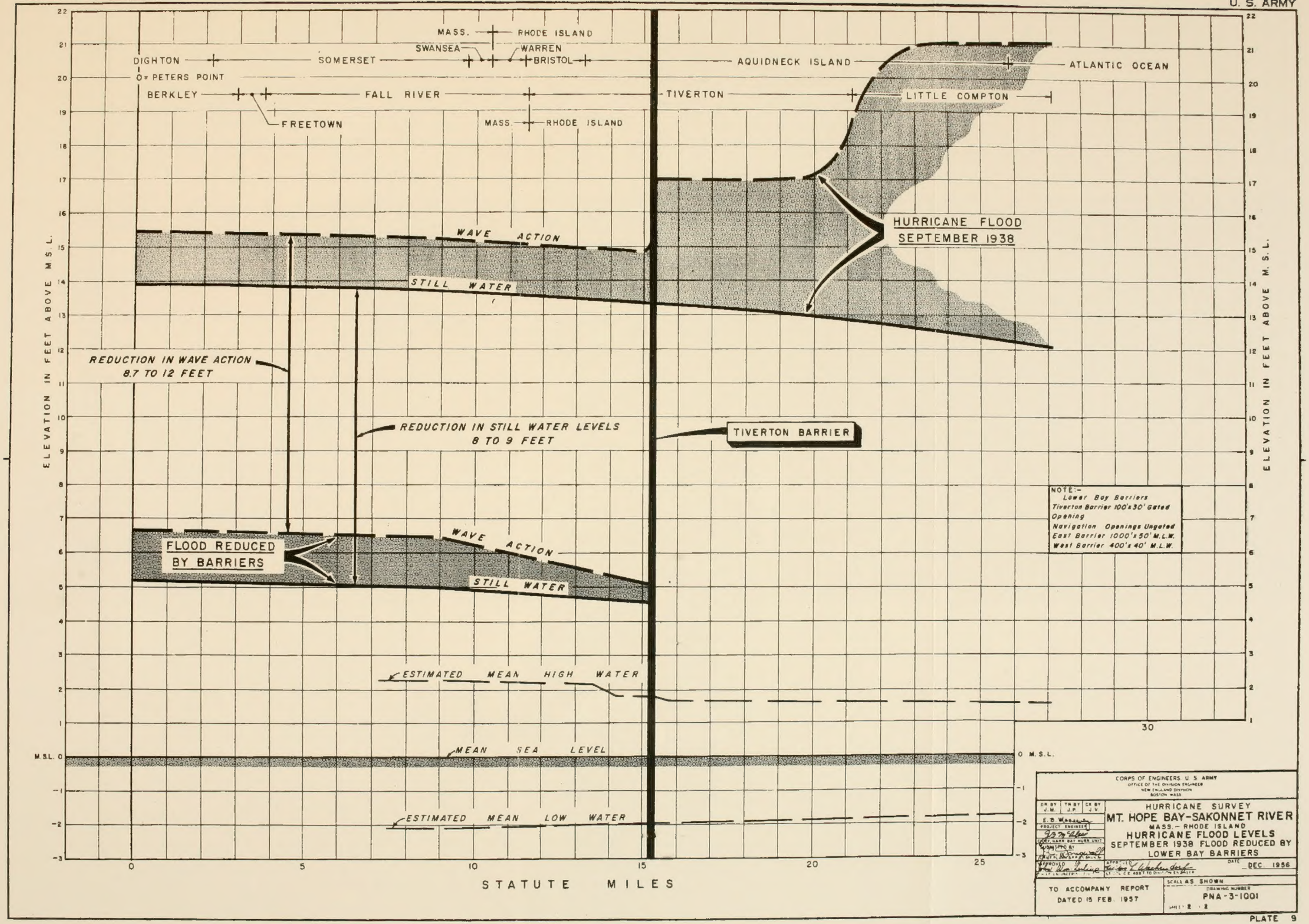


PLATE 9